Geology of the Peel Plateau Area, Yukon and Northwest Territories, Canada

by

Byung I. Chi

May, 1977

BP Exploration Canada Ltd.

CONTENTS

Figures

Measured Sections

Summary

The Peel Plateau study area lies between 65° and 68° N. latitude and between 132° and 136° W. longitude. It contains a thick sequence of sedimentary rocks ranging in age from Cambrian to Cretaceous. This study is concerned with Cambrian to Devonian strata which are considered to have the most potential for hydrocarbon accumulations. All formations are described in detail. Also, published nomenclature and correlations of the Devonian sequences have been revised on the basis of lithology, subsurface information and limited paleonotological data.

BP Canada Ltd. and Francana Oil and Gas Ltd. hold Permit 5693, containing 26,332 acres in the Peel Plateau area, immedidately east of the Trevoir Range. The most attractive formations anticipate under or near Permit 5693 are the Ordovician-Silurian Mount Kindle and the Devonian Cranswick reef plays. The presence of a gentle anticlinal structure on the permit, together with possible reservoir, source and cap rocks suggests the permit may contain excellent hydrocarbon prospects.

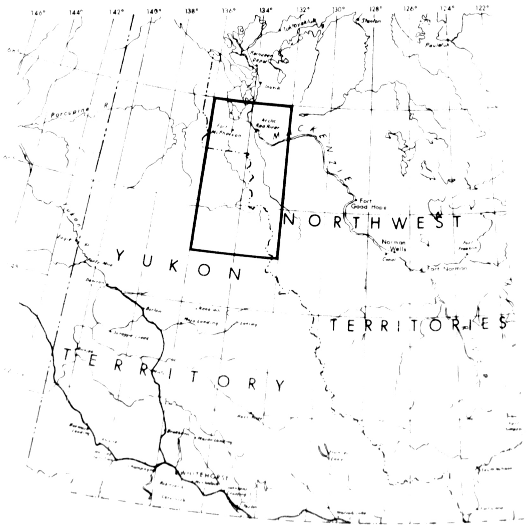
Introduction

This report discusses the results of a field and subsurface study of Lower Paleozoic strata in the Peel Plateau area.

The Peel Plateau geological field party conducted a stratigraphic and sedimentological study in the MacKenzie, Richardson and Wernecke Mountains in 1976. The area covered by the field party lies between 65° and 68° N. latitude and between 132° and 136° W. longitude (Figure 1). A total of 43,990 feet, representing 19 sections in the MacKenzie Mountains, 6 sections in the Richardson Mountains and 2 sections in the Wernecke Mountains was measured and described (Figure 2). Stratigraphic information obtained from outcrop examination is presented in 26 composite sections (Figures 19 to 45). The locations of outcrops examined are shown on Figures 2 and 4.

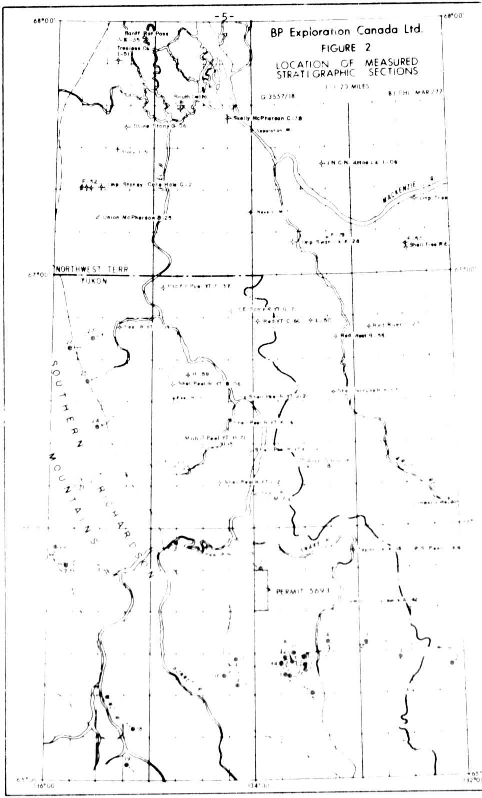
Outcrop samples were collected at every major lithological change for a detailed microscopic study. Fossil collections also were made wherever possible. Microfossil samples were collected at several critical horizons to determine the age of the strata. Lithological and palynological samples were used to determine the hydrocarbon source quality, source type and degree of thermal maturity of strata in the Peel Plateau area. The positions of the lithological, palynological and geochemical samples are shown on the composite stratigraphic sections.

All subsurface information available prior to April, 1977 was incorporated into the results of field investigations. Much of the subsurface data is based on the examination of cutting samples, cores and mechanical logs. A set of eight isopach maps (Figures 5 to 12), representing strata ranging in age from Ordovician to Upper Devonian, is presented. The maps show thickness, distribution and significant facies changes. An area of interest for petroleum potential has been outlined on the accompanying isopach maps. A few important exploratory wells and outcrop sections are presented on a series of five cross-sections (Figures 13 to 17) in order to demonstrate the suggested nomenclature and stratigraphy. One structural cross section (Figure 18) from the Richardson Mountains to Peel Plateau also shows some of the changes in nomenclature accompanying the facies changes. The available and accepted published nomenclature is used as much as possible and a few new lithological units are introduced in this study. (Figure 3).



FIGURE

LOCATION MAP



BP Exploration Canada Ltd.
FIGURE 2
LOCATION OF MEASURED STRATIGRAPHIC SECTIONS
1" = 20 MILES
B.I. CHI MAR/77

Purpose of the Survey

This study was initiated to obtain specific geological information on the Lower Paleozoic strata around the Peel Plateau area and to apply this information in the evaluation of the petroleum potential of the area, and specifically, permit 5693. Permit 5693 is located immediately east of the Trevoir Range (latitude 65° 40' - 65° 50'N. and longitude 133° 52' 30" - 134° 00' W.), contains 26,322 acres and is held jointly by BP Canada Ltd. (86.363%) and Francana Oil and Gas Ltd. (13.637%). The main objectives of the study were to determine and/or obtain the following:

1. Economic potential of the Paleozoic strata.
2. Nature of the facies boundary between shelf carbonates and basinal shales.
3. Characteristics of potential reservoir rocks.
4. Geochemical and biostratigraphical information.
5. Regional correlation, precise dating and nomenclature of Devonian strata.

Field Work

Geological field investigations were conducted in the Peel Plateau area during the summer of 1976. The party was supported in the field by a Bell Jet Ranger"206" B helicopter provided by Okanagan Helicopters Ltd. and a Twin Otter chartered from Gateway Aviation Ltd. Field work was accomplished from a base camp at Margaret Lake. The party stayed in the field for 45 days from July 2 to August 15. During this period 33 days could be fully used for field work, 5 days were occupied by moving and making camp and 7 days were lost due to poor weather.

All members of the party stayed in the field from the beginning to the end of field work and performed their tasks cheerfully. The party was composed of the following personnel:

Byung Chi	Geologist, Party Leader
Marcel Loos	Geologist
David Worsick	Assistant Geologist
Rob Adamowicz	Assistant Geologist
Eddie Furlotte	Cook
Mike Poole	Okanagan Helicopter Pilot
Robert Mogk	Okanagan Helicopter Engineer

Acknowledgements

Sincere thanks are extended to Rob Adamowicz, David Worsick, Eddie Furlotte, Mike Poole and Robert Mogk for their assistance in the field. Marcel Loos encouraged me through numerous stimulating discussions and supplied much valuable data. Tom Birnie read the manuscript and offered valuable comments.

Stratigraphy

Figure 4 shows the regional surface geology of the area covered in this study. Cretaceous strata and Quaternary deposits form the major part of the bedrock, except along the Richardson Mountains to the west and the MacKenzie Mountains to the south, where a thick series of Paleozoic strata crop out. Paleozoic strata are present in the sub-surface at depths ranging from less than 100 feet to more than 3,000 feet, and are buried by Cretaceous or younger formations. Paleozoic strata underlying the area progressively thicken westward from about 9,000 feet in the Ontaratue H-34 well to in excess of 20,000 feet in the Richardson Mountains.

Figure 3 shows the stratigraphic correlation and nomenclature of the Peel Plateau area, some of which is newly defined. It has been compiled from the present study and published information (A. W. Norris, 1968; Lenz and Pedder, 1972; Ludvigsen, 1972; Perry et al, 1974; McQueen, 1975; D. K. Norris, 1975). Five stratigraphic cross sections (Figures 13, 14, 15, 16 and 17) and one structural cross section (Figure 18), also show some of the changes in nomenclature accompanying the facies changes.

Lower Paleozoic and Devonian strata in the study area display a major facies change from shelf carbonates in the east to basinal shales in the west. The shelf carbonates, ranging in age from Late Cambrian to Middle Devonian, record alternating transgressions and regressions that have resulted in unconformity-bounded stratigraphic successions (Figure 3). In the shale basin, graptolitic shales and argillaceous limestones, representing the age equivalents of the shelf carbonates, show a reasonably complete stratigraphic section (Jackson and Lenz, 1962). Only Middle Devonian strata are reported to be missing (Bassett and Stout, 1968; Lenz, 1972), but it is not known whether this represents non-depositional conditions, erosion or lack of paleontological data.

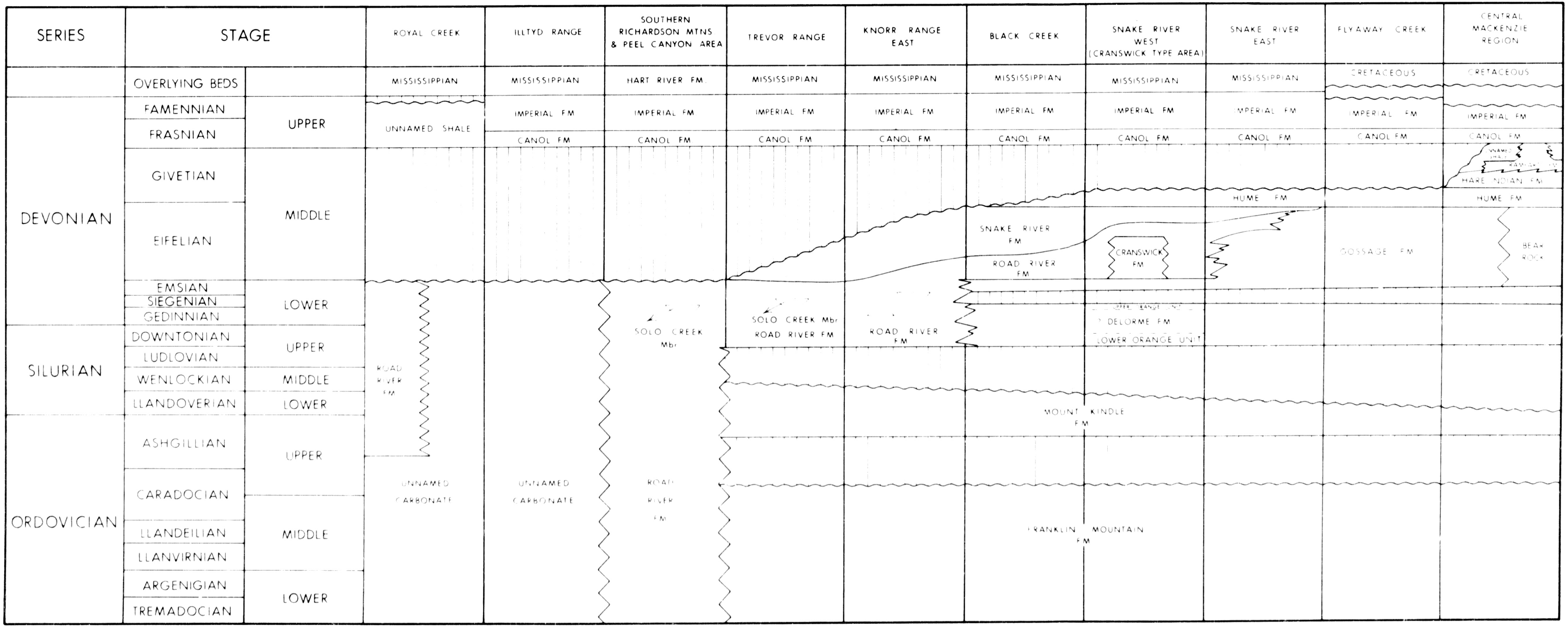

SERIES
STAGE
ROYAL CREEK
ILLTYD RANGE
SOUTHERN RICHARDSON MTNS & PEEL CANYON AREA
TREVOR RANGE
KNORR RANGE EAST
BLACK CREEK
SNAKE RIVER WEST (CRANSWICK TYPE AREA)
SNAKE RIVER EAST
FLYAWAY CREEK
CENTRAL MACKENZIE REGION
OVERLYING BEDS
MISSISSIPPIAN
HART RIVER FM.
CRETACEOUS
DEVONIAN
FAMENNIAN
FRASNIAN
UPPER
UNNAMED SHALE
IMPERIAL FM
CANOL FM
GIVETIAN
EIFELIAN
MIDDLE
HARE INDIAN FM
HUME FM
SNAKE RIVER FM
ROAD RIVER FM
CRANSWICK FM
GOSSAGE FM
BEAR ROCK
EMSIAN
SIEGENIAN
GEDINNIAN
LOWER
SOLO CREEK Mbr
ROAD RIVER FM
DELORME FM
LOWER ORANGE UNIT
SILURIAN
DOWNTONIAN
LUDLOVIAN
WENLOCKIAN
LLANDOVERIAN
MOUNT KINDLE FM
ORDOVICIAN
ASHGILLIAN
CARADOCIAN
LLANDEILIAN
LLANVIRNIAN
ARGENIGIAN
TREMADOCIAN
UNNAMED CARBONATE
FRANKLIN MOUNTAIN FM

FIGURE 3

Upper Paleozoic sediments consist almost entirely of sandstones, siltstones and shales of Upper Devonian to Mississippian age.

Precambrian

No attempt has been made to study Precambrian strata in outcrop. Only one well, the Atlantic et al Ontaratue H-34 has penetrated Precambrian metasediments. They consist of 3,430 feet of siltstones, shales, argillites and quartzites. The strata encountered in the well probably represent the Tindir Group which is exposed at anumber of localities along the Nahanni and Keele Ranges.

Cambrian

Cambrian rocks are believed to be widespread within the study area, but have not been encountered in any wells. In the only well to be drilled deep enough, Ontaratue H-34, Cambrian strata are missing and Ronning dolomite appears to rest directly on Proterozoic shales. Cambrian rocks are represented by 4,000 to 7,000 feet of interbedded shales, sandstones and limestones at outcrop to the southwest of the study area (Fritz, 1974). According to Fritz (1974), Upper Cambrian strata are probably separated from Middle Cambrian strata by an unconformity. But this is difficult to prove because of a lack of fossils and the presence of faults at critical horizons. In the present study, approximately 897 feet of dolomites with minor, interbedded shales underlying the Ronning Group at the 76-A section (Figure 23, Plate 2), are tentatively dated as Cambrian in age.

Ordovician and Silurian

Ronning Group

The name "Ronning Formation" was proposed by Link, in an unpublished report of a thick dolomite sequence of presumed Silurian age on Mount Ronning, in the vicinity of Macdougal Canyon. Hume and Link (1945) and Hume (1954) raised the Ronning Formation to group status for the same stratigraphic interval.

Norford and Macqueen (1975) have shown that the Franklin Mountain and Mount Kindle units are recognized clearly within the type section of the original "Ronning Formation" at Dodo Canyon in the MacKenzie Mountains. In this study, no attempt has been made to subdivide the Ronning Group into the Mount Kindle and Franklin Mountain Formations in the subsurface (Figure 5).

Franklin Mountain Formation

Introduction

The name Franklin Mountain Formation was applied by Williams (1922) to a thick, poorly fossiliferous sequence of carbonate strata. The formation overlies "Talus covered beds of the Saline River Formation at its type section near Mount Kindle".

Equivalents of the Franklin Mountain Formation are present in the lower part of the Ronning Formation, as used by Tassonyi (1969) in the subsurface of the study area. Macqueen (1970) and Norford and Macqueen (1975) have shown that the Franklin Mountain is recognizable in outcrops as a sub-Mount Kindle unit of the Ronning Group throughout the Franklin Mountains and Canyon Ranges of the MacKenzie Mountains north of the 64th parallel. Norris (1975) mapped the Franklin Mountain Formation in the study area.

Lithology

Macqueen (1970) subdivided the Franklin Mountain Formation at the type section in Dodo Canyon into three distinct stratigraphic units. In ascending order, these are the cyclic unit, the rhythmic unit and the cherty unit.

The cyclic unit consists of pale yellowish-orange weathering dolomites with very poor porosity and permeability. The cyclic character is best developed in the Norman Range (Macqueen, 1969). Although the cycles are less distinct elsewhere, outcrops of the unit can be recognized easily over its entire area of development.

The rhythmic unit conformably overlies the cyclic unit and consists of strikingly rhythmic alternations of two types of dolomite. The rhythmic unit is characterized by alternations of:

(a) fine to medium crystalline, brownish-grey to light brown, commonly oolitic, locally quartzose dolomite or, rarely, oolitic or bioclastic grainstones and packstones which are either overlain sharply by or grade upward into

(b) very fine crystalline, greyish-orange to brownish-grey, silty dolomite commonly with flat-pebble conglomerate at the top. This unit is distinctive in the field, because it normally exhibits a striped weathering character.

The rhythms, so prominent in outcrop localities in the Franklin Mountains and frontal MacKenzie Mountains, are more difficult to recognize in the Interior Plains and generally are not apparent even in continuous cores from the subsurface. Surface weathering apparently creates differences between the two types of dolomite. In southern Great Bear Plain, the rhythmic unit apparently is absent over a large area, and the Mount Kindle Formation directly overlies the cyclic unit (Balkwill, 1971).

The cherty unit is a distinctive, fine to coarse crystalline, thick-bedded dolomite unit which overlies the rhythmic unit in many parts of the Interior Plains and the Franklin and eastern MacKenzie Mountains. The distinctive characteristics of this unit are the presence of white chert and drusy quartz, silicified oolites and large silicified stromatolites.

Contacts

At the base, the cyclic unit is interbedded with red and green shale and mudstone characteristic of the upper part of the underlying Saline River Formation. The contact, which is gradational and conformable, is chosen arbitrarily at the top of the stratigraphically highest bed of red or green shale or mudstone which is five feet or more in thickness (Aitken et al, 1974).

The cherty unit is overlain by a regional unconformity separating Upper Ordovician basal Mount Kindle beds from underlying Lower Ordovician or older rocks.

Thickness and Distribution

The cyclic unit ranges in thickness from about 150 to 450 feet. The unit is known to occur along, or to the east of the Redstone Arch. No exposure of the cyclic unit occurs in the type section at Mount Kindle. It seems probable that the cyclic unit is covered by talus at the type section. The unit is missing in the area of this study.

The thickness of the rhythmic unit in outcrops in the MacKenzie and Franklin Mountain ranges from about 500 to 1,600 feet, except where it has been levelled by pre-Devonian erosion (e.g. south end MacKay Range). Norford and Macqueen (1975) report that the average complete rhythm is about nine feet thick, although the known range is from two to 26 feet.

In the Atlantic Columbia Carbon Ontaratue H-34 well (66^{o} 23', 132^{o} 05'), the rhythmic unit is present between 7,948 and 9,460 feet.

The thickness of the cherty units are extremely variable, ranging from zero to about 800 feet and are governed mainly by erosion related to unconformities beneath the overlying Mount Kindle Formation, Bear Rock or Gossage Formations, Cretaceous strata, or the present Pleistocene and Holocene erosion surface. The unit is present between 6,970 and 6,500 feet in the Ontaratue H-34 well.

Age

No diagnostic fossils were found in the Franklin Mountain Formation at the type section. The basal beds of overlying Mount Kindle Formation are recessive, slightly argillaceous and contain coral and brachiopods. These strata were included in the Franklin Mountain Formation and were dated as Silurian by Williams (1923, p.78B; 1963, p.233-235), but are considered Late Ordovician by Norford and Macqueen (1975).

The lower part of the formation (the cyclic unit) has not yielded any diagnostic fauna. Aitken et al (1974) have shown that the Saline River Formation is completely gradational to the overlying Franklin Mountain Formation and sharply overlies the well-dated Lower and Middle Cambrian Mount Cap Formation. Therefore, the Saline River Formation either is entirely Upper Cambrian, or is uppermost Middle and Upper Cambrian. Thus, the overlying cyclic unit of the Franklin Mountain can be considered Upper Cambrian. The position of the Cambrian-Ordovician boundary is not known; it may lie within the rhythmic unit, or between the rhythmic and the overlying cherty units.

Mount Kindle Formation

Introduction

The Mount Kindle Formation was described by Williams (1922) from Mount Kindle in the McConnell Range as "a grey magnesian limestone, composed in large measure of the fossilized remains of Silurian coral reefs".

In the original (1922) description of the Mount Kindle Formation and in subsequent studies by Williams (1923,1963), a recessive interval at the top of the Franklin Mountain Formation was identified as the top of the formation. However, Norford and Macqueen (1975) recently interpreted the recessive interval as the base of the Mount Kindle Formation on the basis of the following evidence.

The base of the recessive interval is marked by a shallow erosion surface beneath dolomite beds that contain fragments of chert nodules and an appreciable content of quartz silt. This surface is a significant disconformity that separates the basal, argillaceous dolomite of the Mount Kindle from an underlying, stromatolitic chert bed that is part of the Franklin Mountain cherty unit.

Lithology

Norford and Mcqueen (1975) subdivided the Mount Kindle Formation into three informal members at the type section. The basal member, 68 feet thick,is recessive. It consists of argillaceous grey-weathering dolomite which weathers flaggy, nodular and rubbly. Weathering colours are light grey, light olive-grey, and yellowish-grey. Corals, brachiopods, gastropods and echinoderm debris are present.

The middle, resistant member of the Mount Kindle is 212 feet thick at the type section, and consists of thin-to-thick bedded, brownish-grey weathering dolomite. The dolomite is generally fine to medium crystalline, in part sucrosic,and shows fair to good intercrystalline and vuggy porosity.

Colonial and solitary corals are common in the lower part; many appear to be in growth position.

The upper, recessive member is 615 feet thick and consists of yellowish-brown weathering, micro-to-medium crystalline dolomite. The upper member is less thickly bedded and lacks the abundance of biostromal material that is present in the middle, resistant member. In many of the coarser dolomite units, granular textures indicate derivation from original lime-grainstone or lime-packstone. Local small vugs lined with drusy calcite may represent leached fossils. Colonial and solitary corals, stromatoporoids and pentamerid brachiopods are found in the lower part of this unit, but most fossils are poorly preserved.

The formation exposed at the Solo Creek section of this report (Figure 38, Plate 3) is lacking in the characteristics of the upper and lower members at the type section. However, the strata are similar to those of the middle member and consist of light grey weathering, bedded, massive, very fine to coarse crystalline dolomites. The strata are often fractured and show fair intercrystalline and vuggy porosity. (Plates 5, 6 and 7). Reef developments are present at the Solo Creek and Canyon Range sections, (Norris, 1967, Sec. 5; Plate 4), and consist of silicified fossils including stromatoporoids, corals and brachiopods.

Contacts

The Mount Kindle Formation is underlain by a regional unconformity separating basal Mount Kindle beds from underlying Lower Ordovician or older rocks. The top of the formation is overlain by an unconformity beneath the Delorme Formation.

Thickness and Distribution

Thickness and distribution of the formation in the study area are poorly known due to the lack of deep well control.

The Mount Kindle Formation is widespread in the northern Franklin and eastern MacKenzie Mountains and in the subsurface of the Great Bear Plain, except where removed by pre-Devonian and later erosion. In the Interior Plains, the Mount Kindle outcrops near Great Slave Lake (G.K. Williams, 1974) and in the Hare Indian River-Smith Arm area (Cook and Aitken, 1971). Distribution of the formation in the Interior Plain is affected to a considerable extent by erosion associated with the sub-Bear Rock or sub-Gossage, the sub-Delorme and the sub-Cretaceous unconformities.

Age

In the type area, the basal and middle members of the Mount Kindle Formation contain abundant fossils. These fossils represent the Bighornia-Thaerodonta fauna of Late Ordovician age. Fossils are rare and poorly preserved in the upper member A few pentamerid brachiopods are present in the basal beds; these are Silurian and probably Early or Middle Llandoverian in age, but associated conodonts are dated by Uyeno (Norford and Macqueen, 1975), as Late Llandoverian to Early Wenlockian.

The upper 400 feet of the formation virtually are barren, but could be younger than Llandoverian. In the type section, the Mount Kindle Formation ranges in age from Late Ordovician to Early Silurian (Llandoverian) and possibly higher.

Ordovician and Silurian

Unnamed Carbonate

A thick, resistant carbonate unit is present in Illtyd Ranges within the study area. The outcrops were briefly examined and the strata are tentatively classified as the "unnamed carbonate unit" defined by Norford(1964).

The upper and lower boundaries of the unnamed carbonate unit are reported to be unconformatble (Lenz and Pedder, 1972). However, the contacts of the units are not exposed at the south Illtyd Range section (Figure 36). The total thickness of the unit in the Illtyd Range is in the order of 5,000 feet (Norford, 1964). Approximately 2,100 feet measured at the south Illtyd section probably represent the upper part of the unnamed carbonate unit in the Illtyd Range area.

The south Illtyd Range section (Figure 18, Figure 36). consists of a thick sequence of limestones, which are divisible into three informal units. The basal unit is 225 feet thick and consists of light grey-brown, micritic, thick bedded and massive limestones with occasional birdseye texture. Strata of this unit are lacking in fossils. The middle unit is 973 feet thick. It consists of light brown, generally fine to coarse crystalline, thick bedded, massive and fossiliferous limestones. Traces of vuggy porosity are present. Favosites, stromatoporoids, solitary corals, brachiopods and crinoids are a common framework of the original sediments. Fossiliferous beds are often interbedded with very fine to fine pelletoidal limestone beds. The upper unit is 955 feet thick and consists of light grey, aphanitic limestones with a trace of pelletoidal grains and occasionally common ostracods. Birdseyes and microfractures are commonly present. No megafossils, other than ostracods, were found in this unit.

Thick successions of dolomites and limestones are reported to be present in the Ogilvie, Wernecke, and White Mountains, and in the Keei and Illtyd Ranges (Norford, 1964; Norris, 1975). The unnamed carbonate unit is believed to range in age from late Cambrian to Middle Devonian (Lenz and Pedder, 1972).

Road River Formation

Introduction

The term "Road River Formation" was proposed by Jackson and Lenz (1962) for Upper Cambrian to Devonian strata of alternating dark coloured graptolitic shales, argillaceous limestones and subordinate amounts of chert, dolomite, siltstone and sandstone beds. The type section of the formation is on Tetlit Creek (Figure 44 of this report), a major tributary of the Road River on the east flank of the Richardson Mountains. Later, Norris, A. W. (1968) proposed the term Prongs Creek Formation for the Devonian portion of the original Road River Formation. Norris, A. W. (op.cit) applied the name to the sequence of the dark shales, dark argillaceous limestones, cherts and carbonate debris beds of marine origin which overlies graptolitic shales of the Road River Formation and are in turn overlain by dark, typical cherty beds of the Canol or Imperial Formations. The contact between the Road River and Prongs Creek Formations was drawn immediately above Monograptus yukonensis, Jackson and Lenz, which is the youngest graptolite in the Road River Formation.

Norris, D. K. (1975), and Macqueen (1975) rejected the term Prongs Creek Formation on the basis that the formation is neither a mappable unit nor is there a major lithologic break between the Road River and Prongs Creek Formations. Macqueen (1975) reports that there is no recognizable compositional change across this contact. Furthermore, M. yukonensis is now known to range through most of the Lower Devonian. Therefore, the definition of the formation boundary on the basis of the highest occurrence of graptolites does not coincide with the original placement of the base of the Prongs Creek Formation.

The concept of the Road River Formation, as originally defined by Jackson and Lenz (1962), is retained in this report. The name Solo Creek member is informally proposed for a sequence of megabreccia carbonate debris blocks and beds in the Road River Formation. The type section is located at Solo Creek, immediately west of the Trevoir Range (Figure 38, Plate 18).

Synonyms

1. Lower part of the Battleship Formation in the Snake River area (Ziegler, 1967).
2. Prongs Creek Formation (A.W. Norris, 1968).
3. Cranswick Formation as mapped to the west of the Trevoir fault (D.K. Norris, 1974).
4. Upper member of the Cranswick Formation in the Snake River area (A.W. Norris, 1968).

Lithology

At the type locality, Norford (1964) subdivided the Road River Formation into two thick informal members. The lower member consists of moderately resistant limestones and argillaceous limestones. The upper member is characterized by more recessive shales, argillaceous limestones and bedded cherts. This informal subdivision is apparent at a number of sections reported by Norford (1964). However, the two members are not clearly recognizable in a few sections located near the carbonate shelf margin, such as the Knorr Range East "B" (Figure 34), Knorr Range South East (Figure 35), Solo Creek (Figure 38) and Peel River East (Figure 39) sections.

The formation consists of dark, basinal shales, pelagic limestones, platform-derived megabreccias, clastic limestones, carbonate mounds, and minor amounts of bedded cherts.

The shales are black to dark grey, well bedded, paper thin to 1 inch thick and very bituminous. The shales are often interbedded with thin pelagic limestones and minor bedded cherts (Plate 17). The non-calcareous shales are commonly siliceous and are fissile. However, the carbonate rich shales have poor parting and often contain argillaceous limestone nodules (Plate 16). Graptolites, cephalopods, inarticulate brachiopods, styliolina and tentaculites are common fossils encountered in the shale sequences.

All the pelagic limestones are dark grey, argillaceous lime mudstones and wackestones with pelagic microfossils. The limestones are well bedded, ¼ to 2 feet thick and interbedded regularly with thinner beds of dark shales. The wackestones often show micrograded beds.

The bioclastic limestones are light to dark gray and form many of the thin beds interbedded with the basinal dark shales. Nearly all the very fine to coarse bioclastic limestones show graded bedding. Internal sedimentary structures, other than graded bedding, are horizontal laminations, cross-bedding (Plate 15) and convolute laminations. The complete interval sequence described by Bouma (1962) is occasionally present (Plate 14). The sequence consists of five intervals from bottom (a) to top (e) (Plate 14), as follows:

e. Pelitic interval
d. Upper interval of parallel lamination
c. Current ripple lamination
b. Lower interval of parallel lamination
a. Graded interval

However, various types of partial or incomplete sequences are more commonly encountered. Angular to subangular, coarse to fine bioclastics, shale, chert and limestone fragments are present at the base of each sequence where the graded interval is 1 to 2 inches thick. The bioclastic grains are usually broken crinoids (single, double and cross hole types), brachiopods, stromatoporoids, corals and tentaculites. The contacts of these bioclastic limestone beds with overlying and underlying beds are sharp.

Distinctive, small carbonate mounds were observed in the Road River Formation at a number of localities on the east flank of the Knorr Range. The mounds are individually isolated (plate 20) and appear to be confined to a narrow stratigraphic interval. The carbonate mounds range from less than 25 to a maximum of 100 feet in height and from 40 to 300 feet wide at the base. One carbonate mound was examined in detail (Plate 20) and is approximately 22 ft. high and 60 ft. wide at the base. It is made up of fossiliferous limestones with framework ranging from 15 to 45 percent of rock volume. The framework consists of bulbous stromatoporoids, favosites, solitary corals, amphipora, echinoderm ossicles, bryozoans and algae. The fossils are in a mud matrix with sparry calcite cement.

Megabreccia beds and blocks which are defined here as an informal member of the formation, occur in the Solo Creek (Figure 38), Peel River East (Figure 39) and Road River (Figure 43) sections. The clasts of the megabreccias are poorly sorted, subrounded to angular and fine to large pebble size (Plate 19). The megabreccia beds range in thickness from 2 feet up to 10 feet. The megabreccia blocks are lacking in bedding character, and range in width from a few feet to over 20 feet and in height from 10 feet to over 30 feet (Plate 12). The blocks or beds are always enclosed in the dark colored basinal rocks. The framework of megabreccia beds and blocks consists of broken stromatoporoids, corals, single and double hole crinoids, brachiopods, limestone and chert fragments. The beds are graded or non-graded and have a sharp planar upper and lower boundary (Plate 18). However, the large debris blocks are non graded and show depressed scour on the underlying basinal shales (Plate 19). The upper surfaces of the blocks are always irregular.

The bioclastic grains originated from fossils that indicate a shallow shelf environment. They are interpreted as having been transported basinward as individual sedimentary particles and mixed with basin fossils. Bouma's complete and various types of incomplete sequences probably represent deposition of a single genetic event from a turbiditic current.

Megabreccia beds and debris blocks encountered in the Road River Formation are very similar to those described and summarized recently by Cook et al (1972) and Mountjoy et al (1972). These authors have been interpreting the carbonate debris blocks as indicators of proximity to the margin of reef complex or shelf marginal carbonates. Mountjoy et al

(1972) suggested that "the presence of megabreccia interpreted as debris flows need not imply high relief, active tectonism or steep slopes that are frequently envisioned for these phenomena. They were apparently initiated by earthquakes or tsunamis and transported as submarine debris flow down low slopes in a manner similar to subaerial mudflow".

The carbonate mounds have been interpreted as "small reefs" having developed on the flank of the Bonnet Plume High during Early Devonian time (Lenz, 1972, p.328). This interpretation was challenged recently by Macqueen (1974) on the basis that they lack an adequate frame work and exhibit no lateral facies change, such as core, back-reef and fore-reef. Macqueen (1974) has suggested that "the masses appear to be banks or biostromes - in situ accumulations of pelletoid and other non-skeletal grains and loose calcareous skeletal material which originally may have been continuous". However, Macqueen has difficulty in explaining the present lack of continuity among the carbonate masses. All the carbonate mounds appear to have been deposited as isolated features. Abundant echinoderm ossicles probably formed ecological niches at preferential sites on the sea floor and trapped suspended lime mud, as do t sea grasses of modern carbonate bank environments. It appears that the corals and stromatoporoids have played a minor role in the formation of the carbonate mounds.

Lithologies, sedimentary structures and fauna suggest that the Road River Formation was deposited in a deep water turbiditic marine environment. The darker colored, bituminous shales and minor pelagic limestones indicate deep, poorly oxygenated muddy waters. However, the presence of carbonate mounds in the formation suggest that water depth was shallow, at least locally, to permit a niche for carbonate mound forming organisms.

Contacts

Norford (1964, p.3) reported that the upper contact of the formation at the type locality (Figure 44) is an angular unconformity beneath Upper Devonian Canol shale. There is no physical evidence to support an angular unconformable relationship. In fact, it is a paraconformity rather than an angular unconformity. However, the upper contact at Peel River West section is a low angle angular unconformity (Plate 40). Throughout most of the area beyond the erosional and/or depositional limits of the Hume and Snake River Formations, the formation is paraconformably overlain by Upper Devonian Canol shale. The calcareous graptolitic shales of the Road River Formation can be readily differentiated from the siliceous and non-graptolitic Upper Devonian shales.

Norford (1964) suggested the contact between the two informal members of the Road Ri er Formation is a diachronous facies boundary, on the basis of Tremadoc graptolites zones (Jackson and Lenz, 1962), which occur in the upper part of the lower member on Tetlit Creek and in the lower part of the upper member in the Peel River canyon.

The lower contact is not present at the type section, due to a fault. But at Trail River, Road River and other localities in the Richardson Mountains, a thick sequence of limestone generally present in the lower part of the formation is gradational with shale, siltstone and sandstone of Cambrian age.

Thickness and Distribution

The formation ranges in thickness from zero at the depositional and/or erosional edge to a maximum thickness of more than 8,000 feet in the Richardson trough. In the type section, Jackson and Lenz (1962) measured a total thickness of 2,985 feet, which represents only the upper part of the formation. At the Rock River section (136° 7' 18" W., 66° 48' N.), outside of this study area, a thick section of the formation is 8,700 feet and contains strata from Cambrian to early Devonian in age.

The lower member of the formation appears to be restricted to the Richardson Mountains, but the upper member was deposited over much of Yukon and Northwest Territories. The formation is well exposed in many of the deeply incised streams on the flanks of the Richardson Mountains and near the Snake River along the MacKenzie Mountain front. The vertical distribution of graptolitic zones (Jackson and Lenz, 1962), and subsurface well control suggest that the formation thickens in a westerly direction from the shelf margin to the centre of the shale basin (Figure 8).

Age

According to Norford (1964), dendroid graptolites and trilobites from the lower part of the lower member on Trail River indicate the strata to be Upper Cambrian (Dresbach) in age. The upper part of the lower member at the type section contains Dictyonema spp., which are indicative of lower Ordovician age (Tremadocian) (Jackson and Lenz, 1962). The upper part of the Road River Formation yields Monograptus sp E (M. yukonensis Jackson and Lenz, 1963), which is now known to range through most of the Lower Devonian. Based on brachiopods (Lenz, 1966, 1967), conodonts (Klapper, 1969) and tentaculites (Ludvigsen, 1971) recovered from approximately 200 feet immediately overlying Monograptus yukonensis, the strata are dated as Emsian in age in the Royal Creek and Solo Creek sections. Considering biostratigraphic controls and stratigraphic position of the Road River Formation in the study area, the top of the formation is considered to be latest Emsian or earliest Eifelian in age.

Silurian and Devonian

Delorme Formation

Introduction

An interval of carbonate rocks which separates the Ronning Group from the Gossage Formation appears to be a new mappable unit. These carbonate rocks are lithologically distinct from the overlying and underlying strata. The lithological character and age of the strata in the study area appear to be similar to those of the Delorme Formation, which has its type locality at the headwaters of Pastel Creek in the Delorme Range. At the type section, the name "Delorme" was applied by Douglas and Norris (1961) to a sequence of buff and light brown weathering, thinly bedded limestones, dolomites and shales that overlie the Whittaker Formation and underlie the Camsell Formation. A physical and biostratigraphical correlation of the Delorme Formation from the type section to the study area has not yet been established.

Synonyms

1. Buff unit (Bullock, 1960).
2. Upper orange zone of the Bear Rock Formation, Middle grey zone and Lower orange zone of the Delorme Formation (Ziegler, 1967).
3. Orange weathering dolomite unit of the Gossage Formation (A.W. Norris, 1968).
4. Orange and grey dolomite unit (SDa unit, D. K. Norris, 1975).

Lithology

Within the study area, the formation is marked by a distinct buff to orange weathering unit at both the top and bottom (Figure 13). The two mappable orange members are informally described as Upper and Lower units of the Delorme Formation.

The formation consists of buff to orange weathering, aphanitic to microcrystalline dolomite with minor limestone and shale (Plate 8). The dolomite is medium brownish grey, thin bedded and well laminated. The well laminated strata are often characterized by algal layers (Plate 9), birdseye textures, ripple marks (Plate 11), and mud cracks (Plate 10). Pinpoint and fenestroidal porosity is occasionally present along bedding planes of the laminated strata. The limestones are medium to dark grey, aphanitic, generally tight, argillaceous and thinly bedded. Very fine bioclastic and pelletoidal grains are often present in the limestones. Shales are more common in the Upper Orange Unit, which is characterized by poor outcrop. For the most part, the formation contains few fossils. However, in places, some beds contain thin shelled brachiopods, trilobites, crinoids, gastropods and amphipora. Sedimentary textures encountered in the carbonate rocks indicate deposition in an intertidal - supratidal marine environment. Light coloured interbeds of the shales were probably deposited in a shallow subtidal to intertidal environment. Shallow water depths are suggested by occurrences of bioturbated textures, brachiopods and amphipora.

Contacts

The Delorme Formation disconformably overlies the Mount Kindle Formation in much of the study area. In parts of the MacKenzie Mountains, an unconformity separates basal Delorme beds from underlying Cambrian or older rocks (MacKenzie, 1969 and Aitken and Cook, 1974). The base of the Delorme Formation is characterized by light greenish grey, aphanitic to microcrystalline dolomite and thin interbeds of greenish grey or chocolate brown shales. These strata are always a thick, covered interval with orange weathering color.

The formation is disconformably overlain by the Gossage formation. The top of the formation is picked at the top of the Upper Orange Unit, below a cliff-forming carbonate sequence of the Gossage Formation.

Thickness and Distribution

The Delorme Formation ranges in thickness from a maximum of about 2,300 feet north of North Nahanni River to 175 feet west of Arctic Red River (Gabrielse, et al, 1973; MacKenzie, 1969). Within the study area, the formation is about 1,000 feet thick. It is not present in the Richardson Mountains and Bonnet Plume River areas due to facies change (Figure 6).

Age

No diagnostic fossils were found in the Delorme Formation. However, according to Gabrielse et al (1973), and Norford and Macqueen (1975), the formation was dated as Late Silurian and Early Devonian.

Lower and Middle Devonian

Gossage Formation

Introduction

Tassonyi (1969) proposed the name Gossage Formation for limestones and dolomites, overlying the Ronning Formation and underlying the Hume Formation, in the Anderson and Peel Plains northwest of Fort Good Hope. The type section occurs between 1,871 and 3,460 feet in the Richfield Oil Corp. et al Grandview Hills No. 1 Well, located at 67° 06' N 130° 52' W.

As re-defined in this report, the term Gossage Formation is applied to the carbonate facies of Middle and Lower Devonian strata above the Delorme Formation (see definition in this report), and below the Hume, Snake River, Cranswick and Road River Formations (Figure 3).

Synonyms

1. Dark grey zone of the Bear Rock Formation. (Ziegler, 1967).
2. Strata overlying orange weathering dolomite unit of the Gossage Formation (A.W. Norris, 1968).
3. Strata overlying upper orange zone of the Gossage Formation (Smith, 1970).

Lithology

Tassonyi (1969) recognized three informal members in the Gossage Formation; the lower limestone member, the middle dolomite member and the upper pellet limestone member.

The lower limestone member consists of very pale, creamy brown or buff, aphanitic limestone, with thin interbeds of light green or bluish-green, waxy, non-calcareous shales. Minor beds of light or pale green, aphanitic, slightly argillaceous dolomite also are present. In the type section, this member is 170 feet thick and lies between 3,290 and 3,460 foot depths.

The middle brown dolomite member is generally buff or brown in color, but with some lighter beds, occasionally fairly calcareous, and fine to very fine cyrstalline with some intercrystalline porosity. In the type section, this member is 670 feet thick between 2,620 and 3,290 foot depths.

The upper pellet limestone member is variably argillaceous, buff or light brown, very fine-grained or aphanitic with abundant lime mud matrix. Pellets are up to 1.6 mm in diameter and commonly made of coagulant lumps. Partings of bluish-green, waxy, non-calcareous shale are common. In the type section, this member is 749 feet thick between 1,871 and 2,620 foot depths.

East of the Richardson Mountains within the study area, the lithology of the Gossage Formation is typically that of the upper pellet limestone member and the middle bedded dolomite member. Thin algal laminations and scattered small birdseyes are often present in the limestone beds. Fossils are generally rare in the formation. However, abundant fossils form locally up to 60 percent of the rock volume. They consist of stromatoporoids, favosites, alveolites, billingsastrea, solitary corals, brachiopods, coenites and crinoids with single, double and cross-like axial holes. The amount of dolomite in the formation varies considerably from the type section to the study area and appears to progressively decrease toward the shelf margin as outlined on the accompanying map (figure 7).

Little information is available regarding the exact boundary between Gossage shelf carbonates and Road River basinal shales in the study area. If interpreted as a facies change, it is possible to envision reef development along the shelf margin. The reef facies of the Gossage Formation is termed the Cranswick Formation, discussed elsewhere in this report.

Contacts

According to Bassett (1961), the lower contact is everywhere sharp in the central MacKenzie area and may represent a disconformity. In the central MacKenzie River region and the study area (Chi, unpublished data, cross-section H-H'), a regional unconformity separates the Gossage Formation from older strata. In the Mount Burgess area (66° 02' N, 139° 35-37' W), conglomerate beds of the Gossage Formation disconformably overlie carbonate beds of Middle Ordovician Age.

The upper contact of the Gossage Formation in the central MacKenzie area is conformable with the overlying Hume Formation. East of the Snake River, the upper contact of the formation becomes progressively older, due to a westward facies change (Figure 3). West of the Snake River, the upper contact of the formation is with clean carbonates of the Cranswick formation. The lower part of the Cranswick Formation is older than the Hume Formation; therefore, the upper boundary of the Gossage is diachronous from older in the west and northwest to younger in the east.

Thickness and Distribution

The thickness of the Gossage Formation ranges from less than 200 feet to slightly more than 2,000 feet in the study area. At the type section in the Richfield Oil Corp. et al Grandview Hills No. 1 well, the formation is 1,589 feet thick between the 1,871 and 3,460 foot depth. The formation appears to reach a maximum thickness of 2,025 feet in the Shell Peel R. YT M-69 well. West of the Snake River area, at the Cranswick East section (Figure 28), it is only 153 feet thick.

Age

The age of the Gossage Formation near the type section on MacKenzie River is uncertain due to a lack of diagnostic fossils. Owing to transgression on the unconformable surface of the Delorme Formation, the lower beds of the Gossage Formation become younger eastward. The base of the Gossage Formation overlies the Upper Orange Unit of the Delorme, which has been dated as Early Devonian (Ziegler, 1967).

The top of the Gossage Formation is older than the Hume Formation, which is presumed to be in part of Late Eifelian age. The most distinctive form collected from the Gossage Formation is the large smooth ostracod Maelleritia canadensis which is restricted to the early Eifelian (Norris, 1968). On the basis of relative stratigraphic position (Figure 3) and limited paleontological data, the formation ranges in age from Lower to Middle Devonian.

Cranswick Formation

Introduction

The name Cranswick Formation was proposed by Norris (1968) for a sequence of Middle Devonian limestones and minor shales overlying dolomites of the Gossage Formation and underlying dark shales of the Road River Formation. The type section is located at the MacKenzie Mountain front immediately west of Snake River (Section 8, Figure 26). Norris (1968) created two informal members of the formation. The upper member consists of black, fine-grained limestone and argillaceous limestone, interbedded with black, calcareous shale. The lithological characteristics of the upper member are almost identical to those of the Road River Formation in the study area and it appears to be part of that Formation. Therefore, the term "Cranswick Formation" in this report is limited to only the lower member of the original Cranswick Formation of the type locality.

Synonyms

1. Lower member of the Cranswick Formation (A.W. Norris, (1968).
2. Lower part of the Cranswick Formation around the type locality (D.K. Norris, 1975).

Lithology

The Cranswick Formation consists of light brown to brownish grey, aphanitic to coarse grained, thin bedded to massive limestones with minor shales. The shales are dark grey, calcareous, well bedded, ¼ to ½ foot thick and bituminous. These shales are present near the base of the formation (Plate 23). The aphanitic limestones are dark grey, bituminous well bedded, ½ to 3 feet thick and are characterized by traces of ostracods, crinoid stems, thin-shelled brachiopods and gastropods. Thin algal layers and bridseye textures are often in the laminated strata. The fine to coarse-grained, well-bedded limestones are brownish to dark grey and 1½ to 3 feet thick. The framework commonly consists of bulbous stromatoporoids, solitary corals, thamnopora, amphipora, brachiopods, crinoids and very fine to fine bioclastic grains, which form approximately 30% of the volume of the limestones (Plate 24).

Massive limestones are light to medium brown, coarse-grained and lacking in lamination. The limestones consist of massive and bulbous stromatoporoids, alveolites, billingsastrea stachyodes and medium to coarse grained bioclastics (Plate 26). The framework forms up to 60% of the volume of the limestones. Abundant frame builders form a distinctive marginal facies around most buildups.

The marginal facies is approximately 400 feet long and 20 feet in height (Plate 25). The massive limestones toward the fore-reef facies are influenced by abundant argillaceous materials with two hole crinoids, thin shelled brachiopods and tentaculites (Plate 28). Toward the interior reef facies, the limestones become more bituminous, bedded and decrease in fossil content.

Relatively stable sea-level conditions probably played a major role, at least locally, in the development of small sized carbonate buildups. However, there is a strong possibility that rapid subsidence due to synsedimentary faulting and tilting of the underlying shelf would result in at least some thick reefal development in the Cranswick Formation.

Contacts

The lower contact of the Cranswick Formation is placed at the top of less resistant dolomites of the Gossage Formation (Plate 21). The upper contact is sharp with the dark grey, basinal limestone or black shale of the Road River Formation. The upper contact is not exposed at the type locality. The top of the formation forms the top of the cliff-forming limestones.

Thickness and Distribution

As defined in this report, the formation is 220 feet in the type section (Section 10, Figure 28). The formation ranges in thickness from 121 to 295 feet in the type area. The distribution is poorly understood in the sub-surface beyond the type section area.

Age

On the basis of stratigraphic position and the contained fauna, such as corals, brachiopods and the distinctive two and four-hole crinoids, Norris (1968) assigned the formation an early Middle Devonian age. According to Perry et al (1974), the two-hole crinoid ossicles (?Gasterocoma bicaula Johnson and Lane) commonly occurring in the formation do not define a distinct biostratigraphic unit, although their great concentration occurs in Emsian beds.

Snake River Formation

Introduction

The name Snake River Formation is here proposed for a sequence of Middle Devonian shales and minor limestones which overlie the Gossage and Road River formations and underlie the Hume and Canol formations (Figure 3). The type section is located at the front of the MacKenzie Mountains immediately west of Snake River at 67° 28' N, 133° 36' W (Figure 26, Plate 29; Norris 1968, Section 6). The name is derived from the Snake River, a tributary of the Peel River.

Synonyms

1. Hare Indian Formation of Norris (1968), Section 6, except the uppermost 445 feet between unit 72 and 77 and the lowermost 122.5 feet between unit 1 and 6.
2. Upper part of the Battleship Formation in the Snake River area (Ziegler, 1967).
3. Upper part of the Prongs Creek Formation at the front of the MacKenzie Mountains around Snake River area. (Smith, 1970).
4. Unnamed Devonian shale (Dsh) (Norris, 1975).

Lithology

The formation consists of light greenish brown to dark grey, buff to orange weathering shales and minor limestones. Outcrops are generally poor and recessive (Plate 33). The shales are well-bedded, paper thin to 4 inches thick, waxy, soft and very calcareous (Plate 35). The strata often contain spherical to elongate limestone nodules (2 inches long, 1 inch wide) near the top of the formation. Fossil tracks are often present along the bedding plane of the shales (Plate 34). The aphanitic limestones are very argillaceous, bedded, up to 2½ feet thick and locally show boudinage structure. Bedding striations occur rarely on the surface of argillaceous limestones (Plate 33). Thin, very fine to fine bioclastic limestone beds are present and often show well defined cross bedding (Plate 32). The formation often contains brachiopods, trilobites and solitary corals.

The light colored shales with minor limestones appear to be deposited in a shallow marine environment, as a small mud delta that migrated progressively basinward. A lack of clastic influx with a shallowing of the sea resulted in the deposition of minor limestone beds. Very fine to fine bioclastic grains of thinly bedded limestones likely originated from the shelf carbonates to the east. The thinning of the formation is, in part, probably related to slow sedimentation of very fine clastic particles on the flank of the mud delta.

Contacts

The lower beds of the Snake River Formation are always poorly exposed and recessive. However, the lower contact of the formation is easily recognizable from a distance on the basis of its buff weathering color and recessive nature, in contrast to the underlying black to dark grey shales or limestones of the Road River Formation (Plate 30) and medium brown limestones of the Gossage Formation. At the type locality, the base of the formation is in sharp contact with slightly resistant, black, very argillaceous limestones of the Road River Formation. The upper contact of the formation is placed at the top of buff weathering, recessive shales below cliff-forming fossiliferous limestones of the Hume Formation (Plate 29) or black, siliceous shales of the Canol Formation (Plate 31).

Thickness and Distribution

The thickness of the formation ranges from zero to a measured maximum of 1165 feet at the type section. Thickness variation is due, in part, to pre-Canol erosion and as a direct result of deposition, as demonstrated in Figure 3.

The formation has a bell-shaped, limited areal distribution within the study area. The thicker sections are located immediately west of Snake River at the MacKenzie Mountain front.

Age

Due to the lack of paleontological data, the precise age of the formation is difficult to determine. Because it overlies the Road River Formation, which contains latest Emsian or earliest Eifelian fossils in its upper part, and is overlain by the Hume Formation containing Givetian fossils, the Snake River Formation is considered to be Eifelian or earliest Givetian in age. Ten palynological samples from the formation have been processed for palynomorphs. All the samples were barren, except one sample which contained abundant chitinozoa. The sample (76-BC-5) is located approximately 9 feet below the base of the Canol Formation in the Black Creek section (Figure 30).

Hume Formation

Introduction

The name "Hume Formation" was proposed by Bassett (1961, p. 486) "for the succession of fossiliferous Middle Devonian limestones and, in places, shale that overlies the Bear Rock Formation and underlies the Hare Indian Formation". The type locality is at the front of the MacKenzie Mountains on the east branch of the Hume River at 65° 20' 30'' N, 129° 58' 00"W.

Synonyms

1. Lower Rampart limestone member (Hume and Link, 1945, p.24).

Lithology

Bassett (1961) gave a five-fold lithological description at the type locality. However, Tassonyi (1969) divided the formation into three members. Tassonyi treated Bassett's lowermost three divisions as one single unit, because of frequent facies changes. Tassonyi's three members are easily recognizable in mechanical logs within the study area, except the area colored in blue on the accompanying Hume Isopach map (Figure 10). The upper member consists of brown, very fine to medium-grained, bioclastic limestones with traces of corals and stromatoporoids and argillaceous limestones with traces of ostracods and brachiopods. The middle member is composed essentially of grey to greenish-grey, calcareous shales with thin argillaceous limestones. The lower member consists of brown, micro-grained argillaceous limestones and dark grey argillaceous shales with traces of crinoids, ostracods and brachiopods.

Contacts

The contact of the Hume Formation with the underlying resistant, clean limestone of the Gossage Formation or with the recessive shales of the Snake River Formation is sharp. Bassett (1961, p. 487) reported the contact of the Hume Formation with the overlying Hare Indian Formation is commonly sharp in the central MacKenzie region and shows no evidence of erosion. Within the study area, the upper contact with the Canol Formation is sharp and may be disconformable.

Thickness and Distribution

The Hume Formation is 400 feet thick at its type locality. The thickness of the formation ranges from zero (Figure 30) to approximately 700 feet (Figure 20). The formation is well exposed along the MacKenzie Mountain front within the study area (Plates 29 and 36). The formation is absent in the I.O.E. Tree River H-38 well and in the areas outlined on the accompanying Figure 10, due to erosion and/or non-deposition during pre-Canol time. It has wide distribution and can be recognized in the Horton River area to the north. To the south, it can be traced to the Summit Lake area of the Rocky Mountains in the northeastern British Columbia (Bassett, 1961, p.486). The eastern boundary is defined by the present erosional edge. The western limit is poorly known in the subsurface, but is outlined on the accompanying map based on all available information (Figure 10).

Age

Most Devonian specialists, including Bassett (1961), Lenz (1961), and McLaren (1962), have tentatively dated the Hume Formation as early Middle Devonian. Others, including Miedema (1962), and House and Pedder (1963), favor a late Middle Devonian age. The Hume Formation is older than beds containing the Givetian brachiopod *Leiorhynchus castanea* (Meek), and younger than beds containing echinodrm ossicles dated as Eifelian (Norris, 1968). Norris regarded the Hume Formation as partly Eifelian and partly Givetian on the basis of its diverse mega-fossils and conodonts. Lenz and Pedder (1972, p.31-35) considered that the Hume Formation at Powell

Creek, excepting the uppermost 14 feet, is probably of Eifelian age. Ormiston (1972, 1975 and 1976) also presumes the Hume Formation to be in part of Eifelian age, and in part of Givetian age.

Peel River Formation

Introduction

The name Peel River Formation is proposed for argillaceous limestones and calcareous shales which overlie the Snake River Formation and underlie the Canol Formation (Figure 15). The formation is thought to be entirely time-equivalent to the basinal facies of the Hume Formation (Figure 10). The type section is the Shell Peel R. YT 1-21 well, located at 66° 10' 36'' N, 134° 18' 52'' W. The interval between 4,760 and 5,140 feet at the type well is assigned to this formation. The formation is limited only to the subsurface of the study area (Figure 10).

Lithology

The Peel River Formation consists of medium grey to brownish grey limestones and shales. The limestones are very argillaceous, bedded and micritic and are interbedded regularly with thin beds of medium grey shale. The strata often contain brachiopods, crinoids and ostracods. Sedimentary structures and textures are not mentioned here due to the absence of cored intervals representing the formation in the subsurface. The environment of deposition of the Peel River Formation is interpreted to be quiet marine and below wave base.

Contacts

The lower contact of the formation is conformable with the light greenish brown shales of the Snake River Formation. The contact is easily placed on mechanical logs at the base of an argillaceous limestone or very calcareous shale overlying the less calcareous shale of the Snake River Formation (Figure 15). The upper contact is sharp with the overlying very radioactive, black, siliceous shales of the Canol Formation.

Thickness and Distribution

The formation ranges in thickness from zero to a maximum of 380 feet at the type well. Thickness variations appear to be controlled by pre-Canol erosion. The formation has a limited aerial distribution in the subsurface along the east side of the Richardson Mountains and west of the deposition limit of the Hume Formation (Figure 10).

Age

No paleontological data are available from the Peel River Formation. However, on the basis of its relative stratigraphic position,the formation appears to be in part of Eifelian and in part of Givetian age, which is the time-equivalent of the Hume Formation.

Upper Devonian

Canol Formation

Introduction

The term "Canol Formation" was introduced by Bassett (1961) for the black shale unit which directly overlies the Kee Scarp Formation or the Hare Indian Formation where the Kee Scarp is missing. The type section is located on the northwest side of Powell Creek at the MacKenzie Mountain front (65° 10' 30" N, 128° 46' 30" W).

Synonyms

1. Bituminous "Fort Creek shales in the Ramparts - Carcajou area (Kindle and Bosworth, 1921).
2. Bituminous zone of the Fort Creek Formation (Hume and Link, 1945; Hume, 1954).

Lithology

The formation at the type section consists of dark grey to black, yellow and rusty-brown weathering, siliceous, thin bedded, fissile and predominantly non-calcareous shales (Chi, 1975).

The lithological characteristics of the formation in the study area are similar to those at the type section. The shales are orange-brown and rusty-red weathering,contain ironstone nodules and have bright yellow sulphide and white mineral coatings at scattered intervals. The shales are paper thin to 1 inch thick, fissile and locally interbedded with thin, black chert beds. The Canol beds become cherty toward the Richardson Mountains in the Peel River West section (Figure 22), the Trail River section (Figure 42) and the Tetlit Creek section (Figure 26). The chert beds are black, evenly bedded and up to 3 inches thick. Shales near the base of the formation at the Black Creek section (Figure 30) contain a few tentaculites and styliolina.

Widespread and relatively uniform lithological characteristics of the black shales of the Canol Formation suggest deposition in a stagnant, euxinic marine environment. The occurrences of tentaculites and styliolina in the formation further indicate a subtidal marine environment.

Contacts

The upper contact with the Imperial Formation is fairly sharp and is marked by an influx of greenish-grey siltstone and sandstone in the Imperial Formation. However, the Canol beds are indistinguishable from the Imperial strata in Union Amoco McPherson B-35 well, where the Canol contains considerable siltstone.

All published information appears to suggest a disconformity at the base of the Canol Formation (Plate 38). The Canol beds overlie progressively older Devonian strata, as illustrated on the accompanying stratigraphic correlation chart (Figure 3). In the central MacKenzie area, the contact between the Canol and Ramparts Formations appears to be separated by a minor disconformity (Pedder, 1975). The disconformable contact between the Canol and the underlying Hare Indian and Hume Formations outcropping along the MacKenzie Mountain front has been demonstrated by Norris (1968). Within the study area, the shales of the Canol Formation overlie graptolite bearing beds of the Road River Formation in the Peel River West section (Figure 80, Plate 40). At this locality Monograptus yukonensis (Jackson and Lenz), which is as young as Emsian in age, occurs approximately 80 feet below the top of the Road River Formation. If a Frasnian age assignment for the base of the Canol Formation is correct, Middle Devonian strata are interpreted as absent due to non-deposition or pre-Canol erosion. However, there is also a strong possibility that the base of the Canol beds mark a strongly diachronous facies boundary ranging from Frasnian to Eifelian in age. If the second interpretation can be confirmed by paleontological data, the lower contact of the Canol Formation with underlying Hare Indian, Hume (Plate 39) and Snake River Formations (Plates 31, 41 and 43) is a conformable facies boundary.

Thickness and Distribution

The Canol Formation is 45 feet thick at the type section (Chi, 1975) and ranges in thickness from less than 20 feet to a maximum of 408 feet in the study area (Figure 11). The formation was deposited in all parts of the area studied. However, outside of the study area, the Canol strata are not present in the Imperial Whirlpool No. 1 well and in the MacKenzie Mountain front area, where the Imperial Formation is in direct contact with the Ramparts Formation (Tassonyi, 1969, p.91) or with the older Hume Formation (MacKenzie, 1969, p.225). Tassonyi believes the absence of the Canol can be attributed to non-deposition rather than pre-Imperial erosion. MacKenzie neither gave the exact locations, nor an explanation for the absence of the Canol beds.

Age

Microfossils and macrofossils are lacking in the Canol Formation. Four palynological samples from the formation have been processed for palynomorphs, but all were barren. However, Braun (1966) recovered the conodonts Palmatolepis and Poloylophodonta, sponge spicules and siliceous spheres of radiolarian origin from the formation at Powell Creek. The microfossils have been dated by him as early Late Devonian (Frasnian). Recently, Lenz and Pedder (1972) have confirmed a Frasnian age on the basis of numerous conodont species recovered from the same Powell Creek section. A few tentaculites and styliolina collected near the base of the Canol Formation at the Black Creek section have been sent to specialists for a detailed study to determine any stratigraphic values. The exact age of the Canol beds in the study area has not yet been established.

Imperial Formation

Introduction

The nomenclature and definition of the Imperial Formation has been modified several times since being first recognized by Kindle and Bosworth in 1921 (see Tassonyi, 1969). As redefined by Bassett (1961), it includes all Upper Devonian clastic rocks and minor interbedded limestones that overlie the Canol Formation and are overlain unconformably by Cretaceous strata. The type section of the Imperial Formation is located about 35 miles west of Norman Wells, District of MacKenzie, on the Imperial River at the front of the MacKenzie Mountains (65^{o} 07' N, 127^{o} 51' W).

A detailed stratigraphic study reveals that Upper Devonian strata encountered in the study area are lithologically different from those of the Imperial Formation in the type area. It is anticipated that a new nomenclature will have to be created for the lithologically distinctive, mappable, Upper Devonian clastic unit in the study area. However, the name "Imperial Formation" has been used for the time being to describe Upper Devonian strata, without creating a new nomenclature in this study.

Synonyms

1. Upper part of Fort Creek Shales, and Bosworth sandstone and shale (Kindle and Bosworth 1921, p.44B, 48B).
2. Upper part of Fort Creek Shales and Carcajou Mountain beds (Kindle, 1936, Hume and Link, 1945, 0.34).
3. Upper Fort Creek Shales and Imperial Formation (Hume and Link, 1945, p.34).

Lithology

The lithologic succession at the type locality of the Imperial Formation has been described recently by Chi and Hills (1974). Bassett (1961) recommended that the 361 foot succession of dark grey shales containing small limestone concretions, which are not exposed at the type locality, should be added to the base of the formation.

Within the study area, the Imperial Formation can be divided into three units; a lower shale unit (C), a middle sandstone-shale unit (B) and an upper shale unit (A) (Figures 15 and 16; Plate 44). However, the three units are not recognizable beyond the depositional limit of the middle unit, as outlined on the accompanying map (Figure 12).

The lower unit consists of dark grey, rusty brown weathering, non-calcareous, siliceous and micaceous shales with very occasional thin, interbedded siltstones and minor clay iron nodules (Plate 48). Strata are thin, well-bedded, rich in organic materials and show poorly defined linear markings on the surface of the bedding plane. Many thin siltstone and shale beds are characterized by convolute laminations.

The middle unit consists of conglomerates, sandstones, siltstones and shales. Siltstones are dark greenish grey, rusty brown weathering, well-bedded, 2 to 6 inches thick and often show very low angle cross lamination and flow cast structures. The strata contain abundant, broken plant debris. Sandstone beds exposed along the MacKenzie Mountain front (Plate 45) and the east side of the Richardson Mountains (Plate 46) are yellow to light grey, orange brown weathering, very fine to coarse grained, angular and poorly sorted. The strata are well bedded, 2 to 4 feet thick, hard and non-calcareous. Most grains are quartz, black and green chert, feldspar and rock fragments in a silica cement. However, at the Road River north section sandstones are lacking in silica cement and show some intergranular porosity. Sandstones encountered in Shell Peel River YT I-01 are creamy white, very fine to very coarse, graded, angular to subangular, poorly sorted and show approximately 8 to 15 percent porosity. Interbeds of sandstones, siltstones, and shales show incomplete or complete Bouma (1962) sequences. The sandstones grade upward to siltstone and shale, which form a complete fining cycle (Plate 49). Each cycle ranges from less than one foot to 12 feet in thickness. The sandstones are generally graded (Plate 5), often cross-laminated (Plate 50) and show current structures commonly found as sole marks (Plates 52-58).

Coarse grained conglomerates are well exposed along the east side of the Richardson Mountains at the Trail River and Road River north sections (Figures 42 and 45; Plate 47). Conglomerates contain subangular to rounded pebbles that are up to 7 inches long and are composed of white quartz and white, black and green chert. The pebbles are in a poorly sorted sandstone, siltstone and clay matrix. Conglomerate beds are up to 15 feet thick. A few beds laterally change in thickness and grain si[illegible], and are lenticular in shape. Large load casts, flute casts, grading and wood fragments have been noted in conglomerate beds.

The upper unit consists of dark grey, slightly calcareous to non-calcareous and micaceous shales with interbedded siltstones and very fine sandstones. Organic material and dark carbonaceous specks are commonly present. Strata are well bedded and locally internally convoluted. Sandstones are light to medium grey, non-calceous, poorly sorted, angular and slightly argillaceous. Siltstones are usually present between sandstones and shales, which form a fining upward cycle. Each cycle ranges from less than one foot to six feet in thickness. Locally re-worked shale fragments are present in the siltstone beds.

Fossiliferous sandstone and argillaceous limestone beds, which are reported to occur in the central MacKenzie River region (Tassonyi, 1969; Chi and Hills, 1974) are not present in the study area.

The Imperial strata near the type section area are generally characterized by the coarsening upward patterns. The shale, representing deep water sediments, are successively overlain by siltstones and silty sandstones deposited in a near shore marine environment. This type of coarsening upward pattern is well known from the nearshore or fluvial marine environments of the Mississippi (Kolb and Van Lopik, 1966), Niger (Weber, 1971) and Rhone Rivers (Oomkens, 1967, 1970). The presence of horn corals, brachiopods and crinoids in sandstones and argillaceous limestones, which occur at the top of each cyclic sequence, further suggest a shallow marine environment.

The lithological characteristics of the Imperial strata indicate the formation was deposited progressively from shallow marine at the type section to a deep water marine environment along the Richardson Mountains. The isopach map of the Imperial Formation (Figure 12) suggests deposition in a deep sedimentary basin with an axis roughly parallel to the Richardson Mountains. The shales and minor interbedded siltstones of the lower unit (C) are deposits that result from the slow settling of fine-grained particles in a quiet water. The absence of carbonate in these deposits suggest that deposition may have been in deep water below mineral compensation depths. Since the spore content in sediments progressively decreases with distance from shore in a marine environment, the absence of spores in the lower unit further suggests the unit was deposited in an off-shore marine environment.

The conglomerates, sandstones and shales of the middle unit (B) are characterized by an abundance of graded bedding, current markings, incomplete Bouma sequences, ungraded bedding, and cross-bedding. The unit is interpreted to represent a submarine fan deposited by turbidity currents. The edge of unit B, as outlined on the accompanying isopach map (Figure 12), appears to approximate the inferred depositional limit of the submarine fan. Palynological data and stratigraphic cross section D-D' (Figure 16) indicate that the base of unit B becomes progressively younger from the depocenter near the Trail River section (Figure 24) toward the margin of the submarine fan. The majority of sediments in unit B may have been derived from Lower Paleozoic rocks to the south and southwest.

The lithological characteristics of unit A are very similar to those of unit C, except for minor carbonate in the sediments. These suggest that unit A was deposited above or near carbonate compensation depths in a marine environment.

Contacts

The lower contact of the Imperial Formation with the Canol is not exposed at the type locality. However, the contact is commonly sharp elsewhere and appears to be conformable (Plate 31). According to Bassett (1961), the upper contact of the formation in the Powell Creek, Hume River and Arctic Red River sections is usually marked by basal Cretaceous strata. The formation in the southeast of the study area at the Flyaway Creek section (Figure 19) is overlain by Cretaceous glauconitic sandstone (Plate 42). Norris (1968) reports that along the east flank of the Northern Richardson Mountains (67^{o} 39' N, 136^{o} 18'-20' W; 67^{o} 27'-28' N, 136^{o} 24'-25' 8" W), a basal cherty conglomerate, dated on spores as Permian, overlies the Imperial Formation. Conglomerate beds outcropping near the top of the Imperial Formation at the Road River north section (Figure 45) are tentatively dated as Mississippian in age on the basis of spores. Within the study area, the upper contact of the formation appears to be overlain by Cretaceous, Permian and Mississippian strata.

In the subsurface of the study area, the upper contact of the formation becomes a subject of a personal "pick", where the overlying strata are lacking in lithological contrasts with the upper part of the Imperial Formation.

Thickness and Distribution

The Imperial Formation in the study area ranges in thickness from slightly less than 2,000 feet to more than 6,000 feet (Figure 12). The thickness of the formation in the vicinity of its type locality is about 2,400 feet. Imperial strata or their equivalents were probably deposited throughout the study area. The thickness variation of the formtion may be partly depositional and partly due to sub-Cretaceous erosion.

Age

The age of the Imperial Formation at the type section has been dated as Upper Frasnian on the basis of megaspores from the lowermost bed and low-mid Famennian from the uppermost bed (Chi and Hills, 1976). At Powell Creek, located approximately 7.5 miles northwest from the type section, brachiopods from near the bottom and top of the formation are dated by Lenz and Pedder (1972) as Frasnian and Famennian, respectively. Megaspores and microspores recovered from the lowermost bed of the Imperial Formation at Powell Creek also support a Frasnian age (Chi, unpublished data). Twenty-two palynological samples from the Imperial Formation outcropping along the MacKenzie Mountain front have been processed for palynomorphs. Due to a high degree of carbonization and lack of palynomorphs, no attempt has been made to determine the age of the samples.

Twenty-three palynological samples from the formation outcropping along the east side of the Richardson Mountains yield abundant, well preserved spore assemblages which are useful for age determination. The spore assemblages indicate the Imperial Formation ranges in age from Frasnian to Tournaisian. McGregor (1970) also reported that the top of the Imperial Formation encountered in Shell Peel River YT J-21 is Tournaisian. Within the study area, the top of the formation appears to range in age from low-mid Famennian to Tournaisian. However, the boundary between the Devonian and Mississippian systems has not yet been established.

CONCLUSIONS AND RECOMMENDATIONS

All data obtained during the 1976 field party and subsurface information available prior to April, 1977, have contributed to a better understanding of the stratigraphy and regional geology of the area. The nomenclature and correlation of Devonian sequences in the Peel River area have been revised on the basis of lithology, subsurface information and limited paleontological data.

The most attractive prospects anticipated under or near Permit 5693 are Mount Kindle and Cranswick reef plays. The Mount Kindle Formation exposed at the Solo Creek section has good vuggy porosity in dolomites and appears to be an obvious potential reservoir. Three small Cranswick reefs are known to occur immediately west of Snake River at the MacKenzie Mountain front. If the Cranswick reefs in the subsurface increase in thickness, porosity and size, commercial production of hydrocarbons could be realized. The Road River Formation is considered to be a potential source and cap rock for the Mount Kindle and Cranswick reef plays (see Appendix, Geochemical report). The presence of a gentle anticlinal structure, together with excellent reservoir, source and cap rocks, is believed to enhance the prospectiveness of the permit.

REFERENCES

Aitken, J.S., and Cook, D.G., 1974, Carcajou Canyon Map Area, District of MacKenzie, Northwest Territories. Geol. Surv. Can., Paper 74-13.

Aitken, J.D., Macqueen, R.W., and Usher, J.L., 1973, Reconnaissance Studies of Proterozoic and Cambrian Stratigraphy, Lower MacKenzie River Area (Operation Norman), District of MacKenzie., Geol.Surv.Can., Paper 73-9.

Balkwill, H.R., 1971, Reconnaissance Geology, Southern Great Plain, District of MacKenzie., Geol.Surv.Can., Paper 71-11.

Bassett, H.G., 1961, Devonian Stratigraphy, Central MacKenzie River Region, Northwest Territories, Canada, in Geology of the Arctic (G.O. Raasch, ed.) vol.1, p. 481-498.

Basset, H.G., and Stout, J.G., 1968, Devonian of Western Canada., Internat. Symp. Dev. System, Calgary 1967 (D.H. Oswald, ed.), vol. 1, p. 717-752.

Bouma, A.H., 1962, Sedimentology of Some Flysch Deposits, a Graphic Approach to Facies Interpretation, Amsterdam, Elsevier Pub.Co., 168 p.

Braun, W.K., 1966, Stratigraphy and Microfauna of Middle and Upper Devonian Formations, Norman Wells Area, Northwest Territories, Canada., N. Jb. Geol. Palaont, Abh., vol. 123, p. 247-264.

Bullock, D.B., 1960, Geological Report of MacKenzie and Richardson Mountains, Yukon and N.W.T., Report to Minister, Dept. Northern Affairs & National Resources by Honolulu Oil Corp., open file.

Chi, B.I., 1975, Ramparts Formation and Exploration Potential Between Powell Creek and Imperial Hills, Northwest Territories, Unpublished report, TR510A, 30 p.

Chi, B.I. and Hills, L.V., 1974, Stratigraphic and Paleoenvironmental Significance of Upper Devonian Megaspores, Type Section of the Imperial Formation, Northwest Territories, Canada., Canadian Arctic Geology (J.D. Aitken and D.J. Glass, ed.) Geol. Assoc. Can.-Can. Soc. Pet. Geol. Symposium, p.241-259.

Cook, D.G. and Aitken, J.D., 1971, Geology, Colville Lake Map - Area and Part of Coppermine Map - Area, Northwest Territories, Geol. Surv. Can., Paper 70 - 12.

Cook, H.E., McDaniel, P.N., Mountjoy, E.W. and Pray, L.C., 1972, Allochthonous Carbonate Debris Flows at Devonian Bank (Reef) Margins, Alberta, Canada. Can. Soc. Petrol. Geologists, vol. 20, no. 3, p. 439-497.

Douglas, R.J.W. and Norris, D.K., 1961, Camsell Bend and Root River Map - Areas, District of MacKenzie, Northwest Territories, Geol. Surv. Can., Paper 61-13.

Fritz, W.H., 1974, Cambrian Biostratigraphy, Northern Yukon Territory and Adjacent Areas., Geol.Surv.Can., Paper 74-1, Part A, p 309-313

Gabrielse, H., Blusson, S.L. and Roddick, J.A., 1973, Geology of Flat River, Glacier Lake, and Wrigley Lake Map - Areas, District of MacKenzie and Yukon Territory., Geol. Suv. Can., Mem. 366, 153 p.

Gilbert, D.L.F., 1974, Anderson, Horton, Northern Great Bear and MacKenzie Plains, Northwest Territories;in Future Petroleum Provinces of Canada, (R.G. McCrossan, ed.), Can.Soc. Petrol. Geologists, Mem.1, p.213 -244 (dated 1973).

Henoch, W.E.S., 1961, Geographical Survey of the Lower MacKenzie and Arctic Red River Area, 1960. The Arctic Circular, vol.14, no. 3, p.52-58.

House, M.R. and Pedder, A.E.H., 1963, Devonian Goniatites and Stratigraphical Correlations in Western Canada. Palaeontology, vol. 6, pt. 3, p. 491-539.

Hume, G.S. and Link, T.A., 1945, Canol Geological Investigations in the MacKenzie River Area, Northwest Territories and Yukon. Geol.Surv.Can., Paper 45-16.

Kindle, E.M. and Bosworth, T.O., 1921, Oil-Bearing Rocks of Lower MacKenzie River Valley. Geol.Surv.Can.Sum.Rept. 1920, Pt. B, p. 37-63.

Jackson, D.E. and Lenz, A.C., 1962, Zonation of Ordovician and Silurian Graptolites of Northern Yukon, Canada., Am. Assoc. Pet. Geol., vol. 46, p. 30-45.

Jackson D.E. and Lenz, A.C., 1963, A new species of Monograptus from the Road River Formation, Yukon. Paleontology, vol. 6, part 4, p.751.

Kolb, C.R. and Van Lopik, J.R., 1966, Depositional Environments of the Mississippi River Delta Plain - Southeastern Louisiana in Deltas, (Shirley, M.L. ed.), Houston Geological Society, 17-61.

Kunst, H., 1974, The Peel Plateau;in Future Petroleum Provinces of Canada, (R.G. McCrossan, ed.), Can. Soc. Petrol. Geologists, Mem. 1, p. 245-273 (dated 1973).

Lenz, A.C. 1961, Devonian Rugose Corals of the Lower MacKenzie Valley, Northwest Territories;in Geology of the Arctic, (Raasch, G.O., ed.) vol. 1. p. 481-495.

Lenz, A.C. 1972, Ordovician to Devonian History of Northern Yukon and Adjacent Districts of MacKenzie. Bull.Can.Pet. Geol., vol. 20, p.321.

Lenz, A.C. and Pedder,A.E.H., 1972. Lower and Middle Paleozoic Sediments and Paleontology of Royal Creek and Peel River, Yukon and Powell Creek, N.W.T., XXIV Int. Geol. Congr., Guidebook, Field Excursion A14.

Ludivgsen, R., 1972, Late Early Devonian Dacryoconarid Tentaculites, Northern Yukon Territory., Can.Jour.Earth Sci., vol. 9 p. 297.

MacKenzie, W.S., 1969, Devonian Stratigraphy, District of MacKenzie, Geol.Surv.Can.Paper 70-1, Part A, p. 131.

Macqueen, R.W., 1969, Lower Paleozoic Stratigraphy, Operation Norman. Geol.Surv.Can., Paper 69-1, Part a, p. 238-241.

Macqueen, R.W., 1970., Lower Paleozoic Stratigraphy and Sedimentology, Eastern MacKenzie Mountains, Northern Franklin Mountains., Geol.Surv.Can., Paper 70-1, Part A, p.225-230.

McGregor, D.C., 1970, Biostratigraphic Determinations of Fossils from the Subsurface of the Yukon Territory and the Districts of MacKenzie and Franklin., Geol.Surv.Can.Paper 70-1. Part A, p. 225-230.

McGregor, D.C., 1970, Biostratigraphic Determinations of Fossils from the Subsurface of the Yukon Territory and the Districts of MacKenzie and Franklin., Geol.Surv.Can. Paper 70-15, p.4-8.

McLaren, D.J., 1962, Middle and Early Upper Devonian Rhynchonelloid Brachiopods From Western Canada., Geol.Surv. Can., Bull. 86.

Miedeman, D., 1962, Mid-Devonian Solitary Rugose Corals From the Northwest Territories, M.Sc. Thesis, Univ. of Sask. 1961, Abstract, Can. Min. Jour., June 1, p.99.

Mountjoy, E.W., Coo, H.E. and Pray, L.C., 1972, Allochthonous Carbonate Debris Flows - Worldwide Indications of Reef Complexes, Banks or Shelf Margins., 24th Inter. Geol.Cong., sec. 6, p. 172 - 189.

Norford, H.S. and Macqueen, R.W., 1975, Lower Paleozoic Franklin Mountain and Mount Kindle Formations, District of MacKenzie. Their type sections and regional developments. Geol.Surv. Can.Paper 74-34, 37 p.

Norris, A.W., 1968, Reconnaissance Devonian Stratigraphy of Northern Yukon Territory and Northwest District of MacKenzie., Geol. Surv. Can., Paper 67-53.

Norris, D.K., 1975, Open File #279; unedited Geological synthesis of those parts of Yukon and Northwest Territories covered by map - areas, Hart River, Wind River & Snake River with a composite legend.

Oomkens, E., 1970, Depositional Sequences and Sand Distribution in the Post-Glacial Rhone Delta Complex, in Morgan, J.P. (ed.), Deltaic Sedimentation Modern and Ancient. Soc. Econ. Paleont. and Mineral, Spec. Pub. 15, p.198-212.

Oomkens, E., 1967, Depositional Sequences and Sand Distribution in a Deltaic Complex; A sedimentological investigation of the Post-Glacial Rhone Delta Complex., Geol. en. Mijnb.v.46, p. 265-278.

Ormiston, A.R., 1972, Fuscinipyge, New Middle Devonian Trilobite Genus from the Northwest Territories,Canada., Jour. Paleontology, vol. 46, No. 5, p. 666-674.

Ormiston, A.R., 1975, Humeia, New Middle Devonian Trilbite from Western Canada, Jour. Paleontology, v.49, No. 3, p.494-500.

Ormiston, A.R., 1976, New Middle Devonian Trilobites from Northwestern Canada, Jour. Paleontology, v.50, No. 6, p.1162-1174.

Pedder, A.E.H., 1964, Correlation of the Canadian Middle Devonian Hume and Nahanni Formations by Tetracorals., Paleont., vol. 7, pt. 3, p. 430-451.

Pedder, A.E.H., 1975, Revised Megafossil Zonation of Middle and Lowest Upper Devonian Strata, Central MacKenzie Valley, Geol.Surv.Can.Paper 75-1, part A, p.571-576.

Perry, D.G., Klapper, G. and Lenz, A.C., 1974, Age of the Ogilivie Formation (Devonian) Northern Yukon; Based Primarily on the Occurrence of Brachiopods and Conodonts., Can.J. Earth Sci., vol. 11, p. 1055-1097.

Smith, V.Z., 1968, Geologic Report on the Structure and Stratigraphy of the MacKenzie Basin Area, Yukon and Northwest Territories, Unpublished report, V.Z. Smith Associated Ltd.

Smith, V.Z., 1969, Memorandum Report, Geologic Field Work, Permit 5693. Western Peel Plateau, Yukon Territory, Unpublished report, V.Z. Smith Associated Ltd., 7 p.

Smith, V. Z., 1970, Geologic Report on the Peel and Porcupine Plateau - Arctic Coastal Area, District of MacKenzie and Yukon Territory, Unpublished report, V. Z. Smith Associates Ltd., 113 p.

Tassonyi, E. J., 1969, Subsurface Geology, Lower MacKenzie River and Anderson River Area, District of MacKenzie., Geol.Surv.Can., Paper 68-25.

Weber, K. J., 1971, Sedimentological Aspects of Oil Fields in the Niger Delta., Geol.en.Mujnb., v. 50, p. 559-576.

Willimas, G.K., 1974, Lower Paleozoic, Slave River Map - Area, Disttrict of MacKenzie (NTS 85), Geol.Surv.Can., Paper 74-1, part B, p. 287-290.

Williams, M.Y., 1922, Exploration East of MacKenzie River between Simpson and Wrigley., Geol.Surv.Can.,Summ.Rept., 1921, part B. p. 56-66.

Williams, M.Y., 1923, Reconnaissance Across Northeastern British Columbia and the Geology of the Northern Extension of Franklin Mountain, Northwest Terttitories., Geol.Surv. Can., Summ.Rept.1922, Part B, p.65-87.

Williams, M.Y., 1963, The age of the Mount Kindle Formation of the Franklin Mountains, Bull.Can.Petrol.Geol., vol.11, p.228-237.

Ziegler, P.H., 1967, Guidebook for Canadian Cordillera Field Trip. International Symp. on the Devonian System, Alberta Soc.Petrol.Geol.

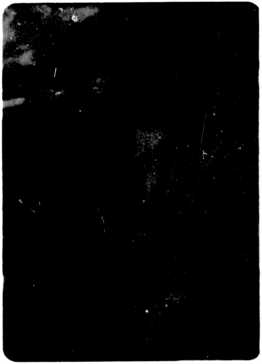


Plate 1

View eastward along MacKenzie Mountain front immediately east of Snake River showing recessive Snake River (S) and Road River Formations (Rd), resistant Gossage (G) and Delorme (D) Formations.

Plate 2

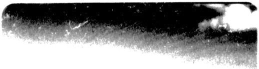
View northward over Lower Orange unit of the Delorme (D) Formation on the sky-line, resistant Ronning Group (R), recessive Road River (Rd) Formation and slightly resistant Cambrian (C) strata about 3 miles west of Snake River (section 5, Figure 23).

Plate 1

View east and along [illegible] Mountain front immediately east of Snake River showing massive [illegible] ([illegible]) and Dead [illegible] Formation (?1), [illegible] (G) and D[illegible] (D) formations.

Plate 2

View northward over Lower [illegible] unit of the D[illegible] [illegible] on the sky-line, [illegible] showing [illegible] massive [illegible] ([illegible]) formation and [illegible] Canyon [illegible] about 3 miles [illegible] River [illegible] 5, [illegible].



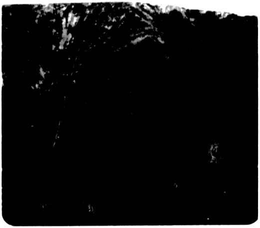


Plate 3

View eastward over Margery Dome on northwest flank of Trevor Range showing various strata of the Running Group. Lower part of the Solo Creek section. (Figure 33).

[illegible]

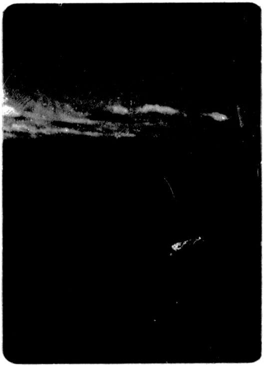


Plate 3

View eastward over Margery Dome on northwest flank of Trevor Range showing porous strata of the Ronning Group. Lower part of the Solo Creek section. (Figure 38).

Plate 4

A porous, dolomitized, stromatoporoid bioherm in the Mount Kindle Formation in the Canyon Range (Norris, 1967, sec.5)

Plate 5 A close-up view of large vugs lined with secondary coarse quartz and calcite crystals in the Mount Kindle Formation at the Solo Creek Section. (Figure 38)

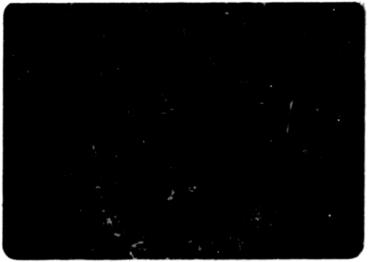


Plate 6 Good vuggy porosity of undetermined origin lined with secondary calcite and quartz in the Mount Kindle Formation at the Solo Creek section (Figure 38).

Plate 5 A close-up view of large vugs lined with secondary coarse quartz and calcite crystals in the Mount Kindle Formation at the Solo Creek Section. (Figure 33)

Plate 6 [illegible] lined with [illegible] calcite [illegible] quartz in the Mount Kindle Formation at the Solo Creek Section (Figure 33).

Plate 7

A close-up view of vugs lined with secondary calcite and quartz in the Mount Kindle Formation of the Solo Creek section (Figure 38).

[illegible] 8

[illegible]

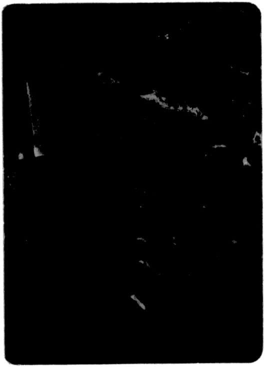
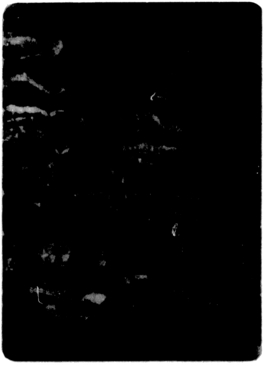


Plate 7

A close-up view of vugs lined with secondary calcite and quartz in the Mount Kindle Formation of the Solo Creek section (Figure 38).

Plate 8

View eastward showing the low part of the Delorme Formation along a major tributary stream approximately 3 miles west of Snake River. (Figure 28).



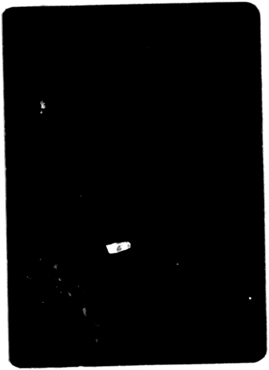


Plate 9

Well laminated strata showing algal layers and birdseye textures in the Delorme Formation at the Snake River East "B" section. (Figure 22).

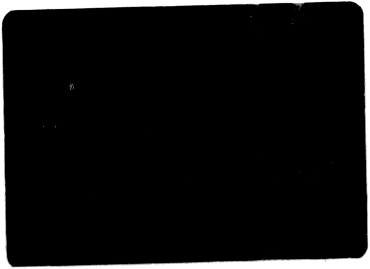


Plate 10 Mud cracks on the top of well laminated dolomite of the Delorme Formation at the 76 A section. (Figure 23).

Plate 9

Well laminated strata showing algal layers and birdseye textures in the Delorme Formation at the Snake River East "B" section. (Figure 22).

Plate 10 Mud cracks on the top of well laminated dolomite of the Delorme Formation at the 76 A section. (Figure 23).

Plate 11 Well laminated strata with ripple marks in the Delorme Formation at the 76A section. (Figure 23).

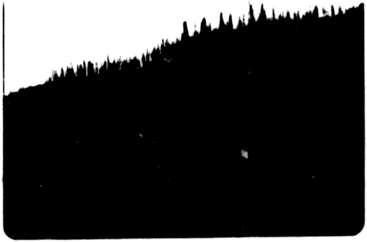


Plate 12 Megabreccia blocks in the Road River Formation at the Peel River East section. (Figure 39).

Plate 11 Well laminated strata with ripple marks in the Delorme Formation at the 76A section. (Figure 23).

Plate 12 Megabreccia blocks in the Road River Formation at the Road River East section. (Figure 39).

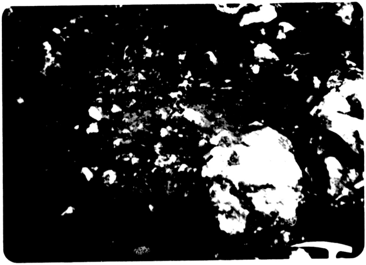


Plate 13 A close-up view of megabreccia blocks showing poorly sorted, subrounded to angular and fine to large pebble size grains in basinal, black shale matrix at the Peel River East section. (Figure 39)

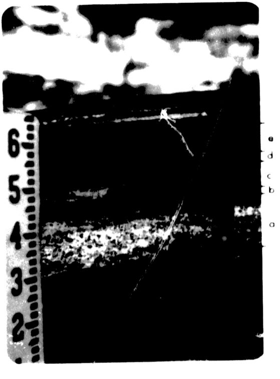


Plate 1

Basal incomplete turbidite sequence showing five inter- vals fr[illegible] [illegible] t[illegible] [illegible] at the Royal Creek Section ([illegible] 37).

Plate 13 A close-up view of megabreccia blocks showing poorly sorted, subrounded to angular and fine to large pebble size grains in basinal, black shale matrix at the Peel River East section. (Figure 39)

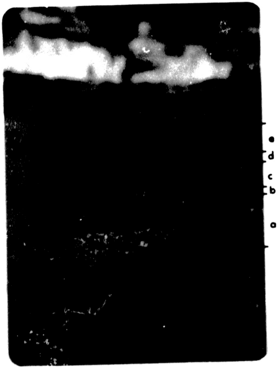


Plate 14

Bouma's complete turbidite sequence showing five intervals from'a'to'e'at the Royal Creek Section (Figure 37).

Plate 15 Bioclastic limestones in the Road River Formation showing well-defined cross-bedding at the Royal Creek Section. (Figure 37).

Plate 16

Pelagic limestone nodules in the black shales of the Road River Formation at the Peel River West section. (Figure 40).

Plate 15 Bioclastic limestones in the Road River Formation showing well-defined cross-bedding at the Royal Creek Section. (Figure 37).

Plate 16

Pelagic limestone nodules in the black shales of the Road River Formation at the Peel River west section. (Figure 40).

Plate 17

Interbedded shales, limestones and cherts of the Road River Formation between 1817 and 1937 feet at the Royal Creek section. (Figure 37).

Plate 17

Interbedded shales, limestones and cherts of the Road River Formation between 1817 and 1937 feet at the Royal Creek section. (Figure 37).

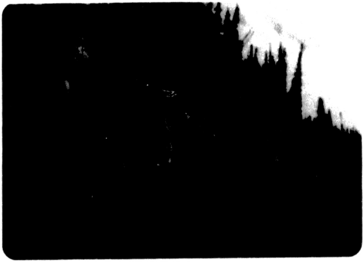


Plate 18 Megabreccia carbonate beds showing a sharp planar lower boundary with underlying black shales of the Road River Formation at the Solo Creek Section. (Figure 38).

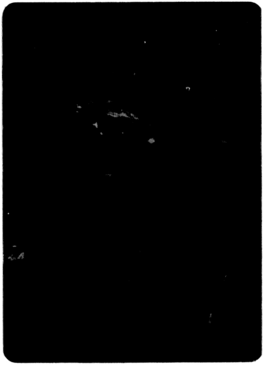


Plate 19

A close-up view of megabreccias showing poorly sorted, sub-rounded to angular and fine to pebble size framework which consists of broken stromatoporoids, corals, limestone and chert fragments in the Road River Formation at the Solo Creek Section. (Figure 38).

Plate 20 An isolated carbonate mound representing one of a series exposed along a northerly trending stratigraphic interval of the Road River Formation in the eastern Knorr Range.

Plate 19

A close-up view of megabreccias showing poorly sorted, subrounded to angular and fine to pebble size framework which consists of broken stromatoporoids, corals, limestone and chert fragments in the Road River Formation at the Solo Creek Section. (Figure 38).

Plate 20 An isolated carbonate mound representing one of a series exposed along a northerly trending stratigraphic interval of the Road River Formation in the eastern Snore Range.

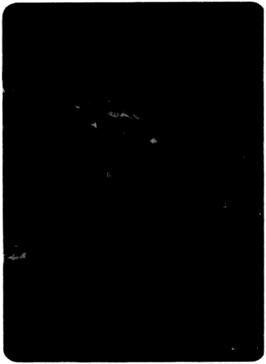


Plate 19

A close-up view of megabreccias showing poorly sorted, subrounded to angular and fine to pebble size framework which consists of broken stromatoporoids, corals, limestone and chert fragments in the Road River Formation at the Solo Creek Section. (Figure 38).

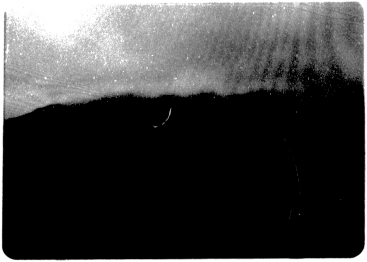


Plate 20 An isolated carbonate mound representing one of a series exposed along a northerly trending stratigraphic interval of the Road River Formation in the eastern Knorr Range.

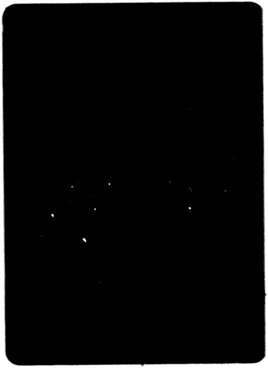


Plate 21

View eastward over the type section of the resistant Cranswick Formation (C), on the skyline, poorly exposed Gossage (G) and Delorme (D) Formations approximately 4 miles west of Snake River just north of MacKenzie Mountain front. (Figure 26).

Plate 22 View westward over a Cranswick reef showing approximately 70 feet of build-up above well laminated carbonate platform approximately 1 mile southwest of the Cranswick type section.

Plate 21

View eastward over the type section of the resistant Cranswick Formation (C), on the skyline, poorly exposed Gossage (G) and Delorme (D) Formations approximately 4 miles west of Snake River just north of MacKenzie Mountain front. (Figure 26).

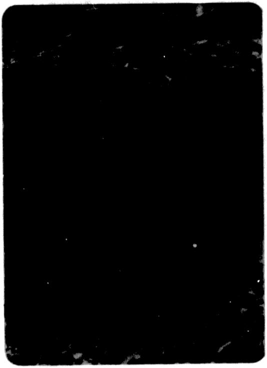
Plate 22 View [illegible] of Cranswick [illegible] showing [illegible] above well [illegible] approximately 1 mile southwest of the Cranswick type section.

Plate 23

Dark gray shales and well bedded limestones near the base of the Cranswick Formation at the type section (Figure 26).
C-Cranswick Formation
G-Gossage Formation

Plate 23

Dark gray shales and well bedded limestones near the base of the Cranswick Formation at the type section (Figure 26).
C-Cranswick Formation
G-Gossage Formation



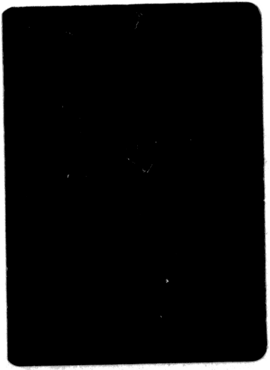


Plate 24

Limestone (packstone) of the Cranswick Formation showing bulbous stromatoporoids, solitary corals, thamnopora, amphipora, brachiopods, crinoids and bioclastic grains in mud matrix at the Cranswick type section. (Figure 26).

Plate 25 View northward over a Cranswick reef showing the marginal facies of the reef approximately ½ mile south of the Cranswick type section. (Figure 25).

Plate 26

A close-up view of the marginal facies of the reef (Plate 25) showing massive stromatoporoids, alveolites, billingsastraea, and medium to coarse grained bioclastics.

Plate 25 View northward over a Cranswick reef showing the marginal facies of the reef approximately 1 mile south of the Cranswick type section. (Figure 25).

Plate 26

A close-up view of the marginal facies of the reef (Plate 25) showing massive stromatoporoids, alveolites, [illegible] sections, and [illegible] coarse [illegible] clastics.

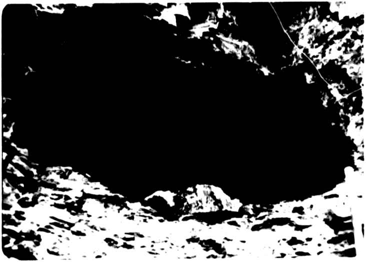


Plate 27 A large cavernous porosity at the type section of the Cranswick Formation. (Figure 26).

[illegible]

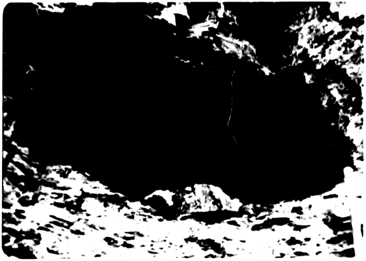


Plate 27 A large cavernous porosity at the type section of the Cranswick Formation. (Figure 26).

Plate [illegible] A close-up view of the fore-reef facies of the reef (Plate 27) showing [illegible] of abundant [illegible] with [illegible] crinoids, thin-shelled brachiopods and tentaculites.

Plate 27 A large cavernous porosity at the type section of the Cranswick Formation. (Figure 26).

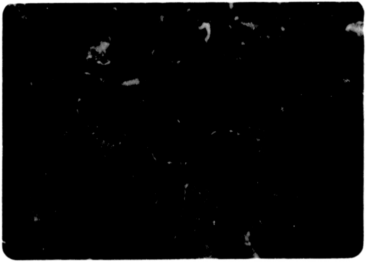


Plate 28 A close-up view of the fore-reef facies of the reef (Plate 25) showing influence of abundant argillaceous material with two hole crinoids, thin shelled brachiopods and tentaculites.

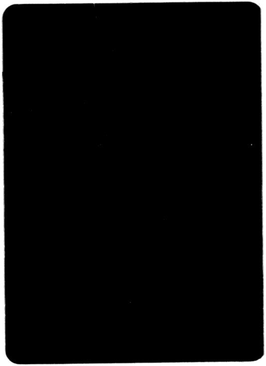


Plate 29

View northward over the resistant Hume Formation (H) on the skyline, and the recessive Snake River Formation (S) on the north side of unnamed tributary stream approximately 4 miles west of Snake River. (Figure 26)

Plate 30 View eastward along MacKenzie Mountain front immediately west of Snake River showing the Snake River (S) and Road River (R) Formations.

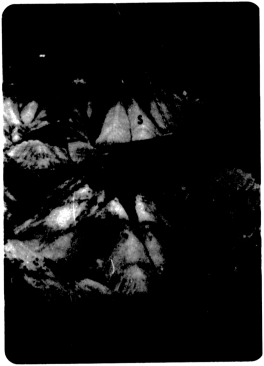


Plate 29

View northward over the resistant Hume Formation (H) on the skyline, and the recessive Snake River Formation (S) on the north side of unnamed tributary stream approximately 4 miles west of Snake River. (Figure 26)

Plate 30 View eastward along Mackenzie Mountain front immediately west of Snake River showing the Snake River (S) and Road River (R) formations.

Plate 31 View northward over the Imperial (I), Canol (C) and Snake River (S) Formations at the Black Creek section. (Figure 30).

[illegible]

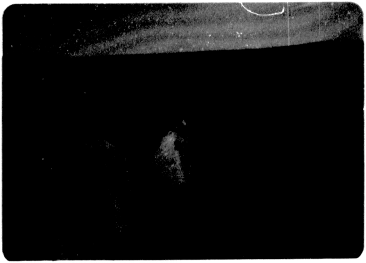


Plate 31 View northward over the Imperial (I), Canol (C) and Snake River (S) Formations at the Black Creek section. (Figure 30).

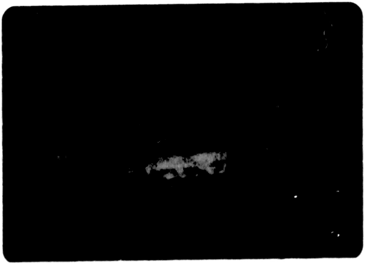


Plate 32 Well-bedded shales and cross-laminated limestone of the Snake River Formation at the Solo Creek Section. (Figure 38)

Plate 33 Bedding striation on the surface of argillaceous limestone of the Snake River Formation at the Black Creek South West section. (Figure 32).

Plate 34 Fossil tracks on the surface of shale at the type section of the Snake River Formation. (Figure 26).

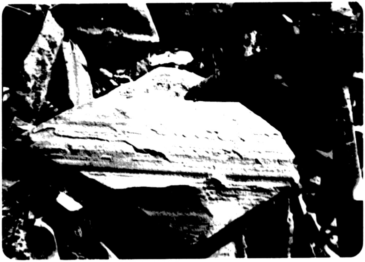
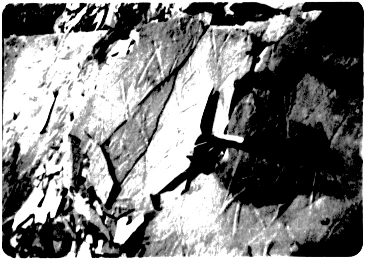


Plate 33 Bedding striation on the surface of argillaceous limestone of the Sadie River formation at [illegible] Creek, South West section. (Figure 32).



[illegible]

Plate 35

Well-laminated, thin shales at the type section of the Snake River Formation. (Figure 26).

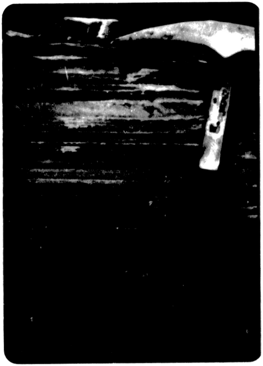
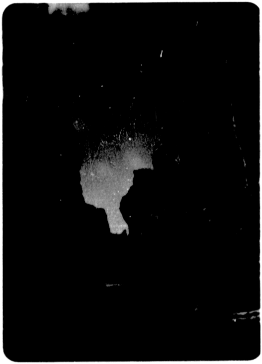


Plate 35

Well-laminated, thin shales at the type section of the Snake River Formation. (Figure 26).

Plate 36

Vertically dipping limestones of the Hume Formation immediately east of the Snake River East "B" section. (Figure 22)



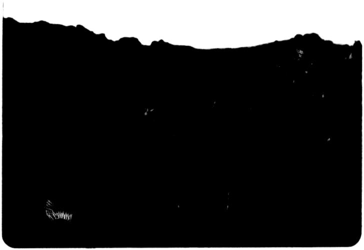


Plate 37 View westward over the unnamed carbonate unit of the South Illtyd Range section. (Figure 36).

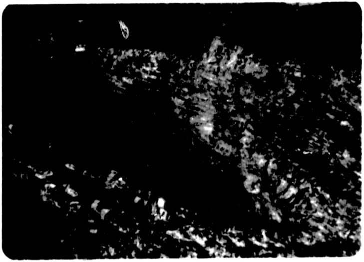


Plate 38 A general view of an unconformable contact between the Canol (C) and Road River (Rd) Formations at the Trail River section. (Figure 42).

Plate 37 View westward over the unnamed carbonate unit of the South Illtyd Range section. (Figure 36).

Plate 39 View northward over steeply dipping resistant limestone of the Hume Formation (H) and recessive shale of the Canol (C) Formation at the Flyaway Creek section. (Figure 19).

[illegible] (Figure 39)

Plate 39 View northward over steeply dipping resistant limestone of the Hume Formation (H) and recessive shale of the Canol (C) Formation at the Flyaway Creek section. (Figure 19).

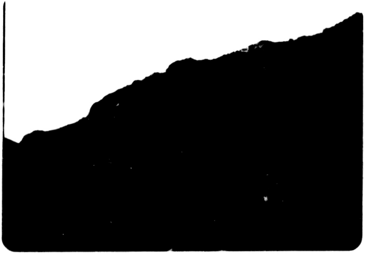


Plate 40 A general view of an angular unconformable contact between the Canol (C) and Road River (Rd) Formations of the Peel River East section. (Figure 39).

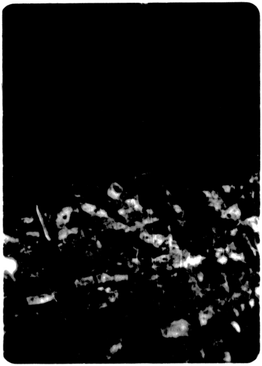


Plate 41

A close-up view of a contact between siliceous black shale of the Canol (C) Formation and calcareous, greyish brown shale of the Snake River (S) Formation at the Black Creek section. (Figure 30)

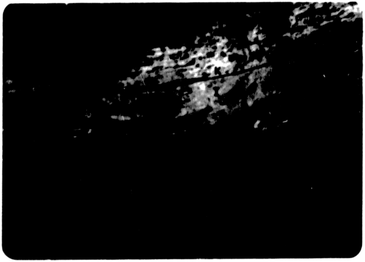
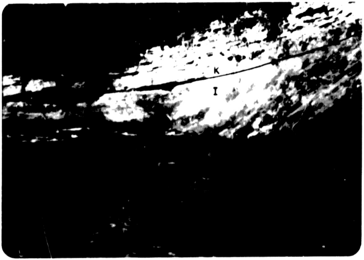


Plate 42 A general view of an unconformable contact between basal Cretaceous glauconitic sandstone (K) and silty shale of the Imperial Formation (I) at the Flyaway Creek section (Figure 19).

Plate 41

A close-up view of a contact between siliceous black shale of the Canol (C) Formation and calcareous, greyish brown shale of the Snake River (S) Formation at the Black Creek section. (Figure 30)



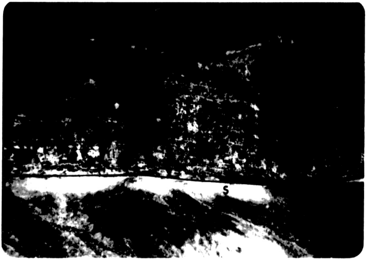


Plate 53 A general view of the Canol (C) and Snake River [illegible] Formations at the Black Creek section (Figure 30).

Plate 43 A general view of the Canol (C) and Snake River (S) Formations at the Black Creek section. (Figure 30).

Plate 44 View northward over the B and C units of the Imperial Formation at the Black Creek section. (Figure 30).

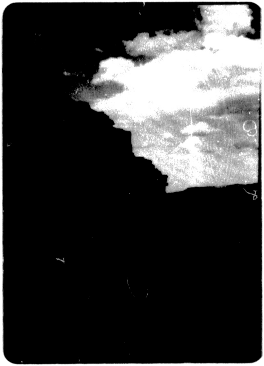


Plate 45

A close-up view of resistant sandstone of the Imperial Formation at the Black Creek section. (Figure 30).

Plate 46

Interbedded, graded sandstone and shale of the Imperial Formation at the Trial River section. (Figure 42).

Rob Adamowicz for scale.

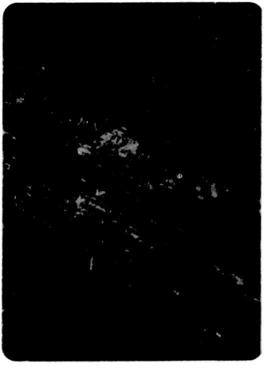


Plate 45

A close-up view of resistant sandstone of the Imperial Formation at the [illegible] Creek section (Figure [illegible]).

Plate 47 Poorly oriented and well rounded pebbles in coarse Imperial sandstone at the Trail River section. (Figure 42).

Plate 48

Interbedded shale and siltstone of the Imperial Formation at the Flyaway Creek section. (Figure 19).

Plate 49

Fining upward cycle from sandstone to shale of the Imperial Formation at the Trail River section. (Figure 42).

Plate 50

Planar cross beds in coarse sandstone of the Imperial Formation at the Trail River section. (Figure 42).

Plate 49

Fining upward cycle from sandstone to shale of the [illegible] Formation at the Trail River section. (Figure 52).

Plate 51

[illegible] of [illegible] Formation [illegible] River north section.
(Figure 45).

Plate 51

Graded sandstone of the Imperial Formation at the Road River north section. (Figure 45).

Plate 52 Flute casts on the under surface of Imperial sandstone at the Trail River section (Figure 42). Current from left to right.

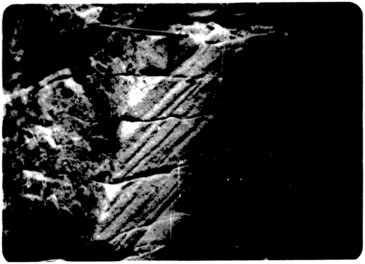


Plate 53 Groove casts (drag marks) on the under surface of Imperial sandstone at the Road River north section. (Figure 45).

Plate 54

Flute casts on base of graded sandstone in the Imperial Formation at the Road River section. (Figure 45). Current parallel to pencil from right to left.

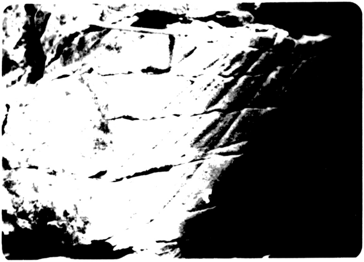


Plate 53 Groove casts (drag marks) on the under surface of Imperial sandstone at the Seal River north section. (Figure 45).

Plate 54

[illegible]

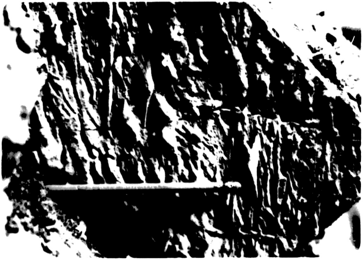
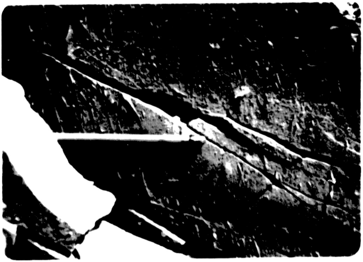


Plate 55. Flute marks and load casts on base of Imperial sandstone at [illegible] River north [illegible]. (Figure 45).



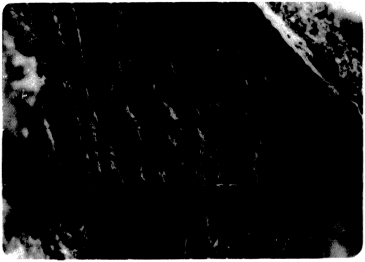


Plate 55 Flute marks and load casts on base of Imperial sandstone at the Road River north section. (Figure 45).

Plate 56 Groove casts and other marks of undetermined origin on base of Imperial sandstone at the Road River north section. (Figure 45).

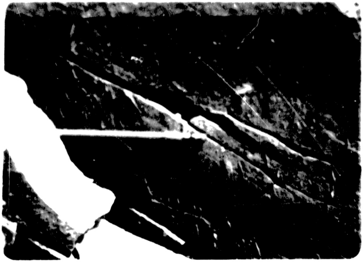


Plate 57

Flute casts or longitudinal ridges produced by current scouring on the under surface of Imperial sandstone at the Road River north section. (Figure 45).

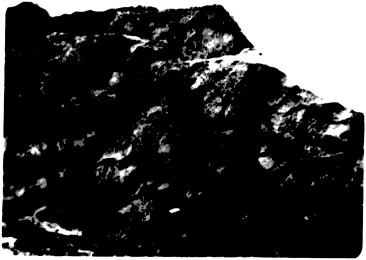


Plate 58 Load casts with crack patterns on the under surface of Imperial sandstone at the Road River north section (Figure 45).

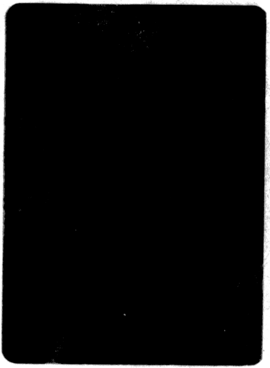


Plate 57

Flute casts or longitudinal ridges produced by current scouring on the under surface of Imperial sandstone at the Road River north section. (Figure 45).

Plate 58 Load casts with random pattern on the under surface of Imperial sandstone at the Road River north section (Figure 45).

Palynological Analysis of Selected Outcrop Samples

Seventy three palynological samples were processed at Geochemical Laboratories (Canada) Ltd. All palynomorphs were identified by the author. The general lithology of the sections studied consists of complexly alternating shales, siltstones, sandstones, conglomerates and argillaceous limestones. Shales and siltstones were only used for the palynological study. An absence of palynomorphs in samples from the Road River, Snake River, Canol and Imperial Formations is interpreted to indicate that the sediments were deposited under offshore - marine conditions. Geographic location, stratigraphic position, formation name and age of the samples are:

Flyaway Creek Section (Figure 19)

1. 76-FCS1, Imperial Fm., 10 feet above the base of the formation.

   Barren

2. 76-FCS-2, Imperial Fm., 77 feet above the base of the formation.

   Barren

3. 76-FCS-3, Imperial Fm., 130 feet above the base of the formation.

   Barren

4. 76-FCS-7, Imperial Fm., 247 feet above the base of the formation.

   Barren

5. 76-FCS-8, Imperial Fm., 272 feet above the base of the formation.

   Barren

6. 76-FCS-9, Imperial Fm., 307 feet above the base of the formation.

   Barren

7. 76-FCS-10, Imperial Fm., 337 feet above the base of the formation

   Barren

8. 76-FCS-11, Imperial Fm., 411 feet above the base of the formation.

Barren

9. 76-FCS-12, Imperial Fm., 422 feet above the base of the formation.

Barren

10. 76-FCS-14, Imperial Fm., 587 feet above the base of the formation.

Barren

11. 76-FCS-15, Imperial Fm., 667 feet above the base of the formation.

Barren

Road River North Section (Figure 45)

12. 76-RRN-3, Imperial Fm., 23 feet above the base of the section.

Ancyrospora sp.

Auroraspora macromanifestus

Calamorspora sp.

Grandispora velatus

Hystricosporites sp.

Lophozonotriletes cristofer (Luber) Kedo

L. spp

Punctatisporites sp.

Spinozonotriletes sp.

age: Late Devonian, Famennian

13. 76-RRN-4, Imperial Fm., 88 feet above the base of the section.

Archeozontriletes sp.

Auroraspora macromanifestus

Calamospora sp.

Lophozonotriletes spp.

Retursotriletes sp.

Stenozonotriletes sp.

age: Late Devonian, Fammenian

14. 76-RRN-5, Imperial Fm., 148 feet above the base of the section.

Archeozonotriletes sp.

Ancyrospora sp.

Broken fragments of Biharisporites sp.

Grandispora velatus

Hymenozonotriletes sp.

Hystricosporites spp.

Knoxisporites sp.

Lophozonotriletes cristofer (Luber) Kedo

L. lebedianensis Naumova

Pustulatisporites sp.

Retusotriletes sp.

Stenozonotriletes sp.

age: Late Devonian, Fammenian

15. 76-RRN-6, Imperial Fm., 238 feet above the base of the section.

Ancyrospora sp.

Auroraspora macromanifestus

Grandisporta velatus

Hystricosporites furcatus

Lophozonotriletes cristofer (Luber) Kedo

L. spp.

Retusotriletes sp.

age: Late Devonian, Fammenian

16. 76-RRN-9, Imperial Formation, 926 feet above the base of the section.

Ancyrospora sp.

Auroraspora macromanifestus

Archaeozonotriletes spp.

Hystricosporites spp.

Leiotriletes sp.

Lophozonotriletes cristofer (Luber) Kedo

16. (cont'd.)

Retusotriletes sp.

Stenozonatriletes sp.

age: Late Devonian, Fammenian

Solo Creek Section (Figure 38)

17. 76-SC-1, Road River Fm.,696 feet above the base of the formation.

Barren

18. 76-SC-3, Road River Fm., 881 feet above t' base of the formation.

Barren

19. 76-SC-4, Road River Fm., 899 feet above the base of the formation.

Barren

20. 76-SC-6, Road River Fm., 921 feet above the base of the formation.

Barren

Black Creek Section (Figure 30)

21. 76-BC-1, Snake River Fm., 80 feet above the base of the section

Barren

22. 76-BC-2, Snake River Fm., 103 feet above the base of the section

Barren

23. 76-BC-5, Snake River Fm., 368.5 feet above the base of the section.

Desmochitina sp

Eisenackitina sp. 1

E. sp. 2

Lagenochitina sp.

age: Middle Devonian, Givetian
The sample lacks in spores. However, it contains abundant chitinozoa assemblages which are similar to those described from the middle Devonian Hamilton Formation by Legault (1973).

24. 76-BC-9, Snake River Fm., 374.5 feet above the base of the section.

Barren

25. 76-BC-12, Canol Fm., 3.5 feet above the base of the formation.

Barren

26. 76-BC-18, Imperial Fm., 125.5 feet baveo the base of the formation.

Barren

27. 76-BC-19, Imperial Fm., 130.5 feet above the base of the formation.

Auroraspora macromanifestus

Grandispora velatus

age: Many forms of palynomorphs are present. However, no attempt has been made to identify individual species due to the high degree of carbonization. Abudant Auroraspora macromanifestus probably suggests a Givetian age.

Peel River West Section (Figure 40)

28. 76-PW-9, Canol Fm., 3 feet above the base of the formation

Barren

29. 76-PW-1, Canol Fm., 32 feet above the base of the formation.

Barren

Road River Section (Figure 43)

30. 76-RR-15, Canol Fm., 1 foot above the base of the formation.

Barren

Royal Creek Section (Figure 37)

31. 76-RC-11, Road River Fm., 1182 feet above the base of the formation.

Barren

Knorr Range East Section (Figure 33)

32. 76-KRE-1, Snake River Fm., 130 feet above the base of the formation.

Barren

33. 76-KRE-2, Snake River Fm., 230 feet above the base of the formation.

Barren

34. 76-KRG-5, Snake River Fm., 580 feet above the base of the formation.

Barren

35. 76-KRE-6, Snake River Fm., 610 feet above the base of the formation.

Punctatisporites sp.

Broken fragments of Chitinozoa

age: Spores rare and poorly preserved, probably Gietian

36. 76-KRE-9, Snake River Fm., 733 feet above the base of the formation

Barren

37. 76-KRE-13, Snake River Fm., 855 feet above the base of the formation.

Barren

38. 76-KRE-23, Imperial Fm., 333 feet above the base of the section.

Barren

Road River North Section

39. 76-RRN-9, Unnamed strata, 11 feet above the top of the Imperial Fm.

Barren

40. 76-RRN-10, Unnamed strata, 46 feet above the top of the Imperial Fm.

Barren

Peel River West "A" Section

41. 76-PW"A"-2, Imperial Fm., 2 feet above the base of the formation.

Barren

42. 76-PW"A"-3, Imperial Fm., 11 feet above the base of the formation.

Barren

43. 76-PW"A"-4, Imperial Fm., 75 feet above the base of the formation.

Barren

44. 76-PW"A"-6, Imperial Fm., 185 feet above the base of the formation.

Barren

45. 76-PW"A"-8, Imperial Fm., 332 feet above the base of the formation.

Barren

Peel River West Section

46. 76-PW-16, Imperial Fm., 100 feet above the base of the formation.

Barren

Flyaway Creek (North) Section (Figure 19)

47. 76-FCN-2, Imperial Fm., 995 feet above the base of the formation.

Barren

48. 76-FCN-4, Imperial Fm., 1220 feet above the base of the formation.

Spores poorly preserved and carbonized. Abundant small spores having less than 50 u in size.

49. 76-FCN-5 Imperial Fm., 1335 feet above the base of the formation.

Barren

50 76-FCN-7, Imperial Fm., 1452 feet above the base of the formation.

Barren

51. 76-FCN-8, Imperial Fm., 2055 feet above the base of the formation.

Barren

52. 76-FCN-9, Imperial Fm., 2175 feet above the base of the formation.

Barren

53. 76-FCN-10, Imperial Fm., 2240 feet above the base of the formation.

Apiculatasporites sp.

Lycospora cf magnifica

Punctatisporites sp.

Stenozonotriletes sp.

age: Upper Devonian

54. 76-FCN-11, Imperial Fm., 2388 feet above the base of the formation.

Punctatisporites glabrimarginatus

Retusotriletes sp.

Stenozonotriletes sp.

age: Spores are rare and poorly preserved

Upper Devonian

55. 76-FCN-12, Imperial Fm., 2423 feet above the base of the formation.

Apiculatatsporites sp.

Punctatisporites sp.

Retusotriletes sp.

age: Spores poorly preserved and carbonized, Upper Devonian.

Trail River Section (Figure 42)

56. 76-TRE-10, Imperial Fm., 772 feet above the base of the formation.

Barren

57. 76-TRE-12, Imperial Fm., 986 feet above the base of the formation.

Barren

58. 76-TRE-13, Imperial Fm., 1239 feet above the base of the formation.

Spores rare, highly carbonized and poorly preserved.

59. 76-TRE-15, Imperial Fm., 1306 feet above the base of the formation.

Spores rare, highly carbonized and poorly preserved.

60. 76-TRE-16, Imperial Fm., 1631 feet above the base of the formation.

Barren

61. 76-TRE-18, Imperial Fm., 1653 feet above the base of the formation

Barren

62. 76-TRE-19, Imperial Fm., 1897 feet above the base of the formation.

Barren

63. 76-TRE-21, Imperial Fm., 2009 feet above the base of the formation.

Barren

64. 76-TRE-22, Imperial Fm., 2102 feet above the base of the formation.

Barren

65. 76-TRE-27, Imperial Fm., 2520 feet above the base of the formation.

Barren

66. 76-TRE-28, Imperial Fm., 2515 feet above the base of the formation.

Barren

67. 76-TRE-29, Imperial Fm., 3264 feet above the base of the formation.

68. 76-TRE-31, Imperial Fm., 4197 feet above the base of the formation.

Barren

69. 76-TRE-35, Imperial Fm., 4818 feet above the base of the formation.

Barren

70. 76-TRE-39, Imperial Fm., 5752 feet above the base of the formation.

Ancyrospora sp.

Auroraspora macromanifestus

Calamospora sp.

Hystricosporites spp.

Lophozonotriletes cristofer (Luber) Kedo

L. spp.

Lophozonotriletes sp.

Verruciretusispora magnifica var. magnifica Owens

Verrucisporites medius var. minutus

age: Late Devonian, Famennian

71. 76-TRE-40, Imperial Fm., 6083 feet above the base of the formation.

Grandispora echinata Hacquebard

Hymenozonotriletes lepidophytus

Hystricosporites sp.

Lophozonotriletes cristofer (Luber) Kedo

L. rarituberculatus

Retusotriletes sp.

age: Late Devonian, Famennian

72. 76-TRE-41, Imperial Fm., 6[illegible]00 feet above the base of the formation.

<u>Archaeozonotriletes</u> <u>literatus</u>

<u>Calamospora</u> sp.

<u>Hymenozonotriletes</u> <u>lepidophytus</u> Kedo

<u>Lophozonotriletes</u> <u>cristofer</u> (Luber) Kedo

<u>L.</u> rarituberculatus

<u>Spinozonotriletes</u> <u>uncatus</u> Hacquebard

<u>Verruciretusispora</u> <u>magnifica</u> var. magnifica

age: Late Devonian, Famennian

73. 76-TRE-42, Imperial Fm., 6328 feet above the base of the formation.

<u>Auroraspora</u> <u>macromanifestus</u>

<u>Grandispora</u> <u>echinata</u> Hacquebard

<u>Grandispora</u> <u>velata</u>

<u>Hymenozonotriletes</u> <u>lepidophytus</u> Kedo

<u>Hystricosporites</u> sp.

<u>Lophozonotriletes</u> <u>cristofer</u> (Luber) Kedo

<u>L.</u> cf <u>rarituberculatus</u>

age: Late Devonian, Famennian

Geochemical Analysis of Selected Outcrop Samples

Twenty geochemical samples were processed at Geochemical Laboratories (Canada) Ltd. to determine the hydrocarbon source quality, source type and degree of thermal maturity of strata in the Peel Plateau area. Geographic location, stratigraphic position and formation name of the samples are:

Road River Formation (Formation A)

Sample number -

1. 76-RR-2, 25 feet above the base at the Road River section (Figure 43).
2. 76-RC-6, 717 feet above the base of the formation at the Royal Creek section (Figure 37).
3. 76-RC-10, 844 feet above Royal Creek Section (Figure 37).
4. 76-RC-11, 1182 feet above Royal Creek Section (Figure 37).
5. 76-RC-20, 1522 feet above Royal Creek Section (Figure 37).
6. 76-RC-27, 2362 feet above Royal Creek Section (Figure 37).
7. 76-SC-7, 504 feet above the base of the formation exposed at the Solo Creek section (Figure 38).
8. 76-PW-7, top of the formation at the Peel River West section. (Figure 40).
9. 76-PRE-9, 1763 feet above the base at the Peel River East section (Figure 39).

Snake River Formation (Formation B)

10. 76-SC-1-C, 460 feet above the base of the formation at the Solo Creek section (Figure 38).
11. 76-KRE-5, 450 feet above the base of the formation at the Knorr Range East section (Figure 33).
12. 76-BC-5, top of the formation at the Black Creek section (Figure 30).

Canol Formation (Formation C)

13. 76-PW-9, base of the formation at the Peel River West section (Figure 39).
14. 76-BC-13, 121 feet above the base of the formation at the Black Creek section (Figure 30).

Imperial Formation (Formation D)

15. 76-RRN-3, 23 feet above the base of the Road River north section (Figure 45).

16. 76-RRN-9, 926 feet above the base of the Road River north section.

17. 76-FC"A"-12, 200 feet below the top of the formation at the Flyaway Creek section (Figure 19).

18. 76-FCS-1, 10 feet above the base of the formation at the Flyaway Creek section (Figure 19).

19. 76-FCS-5, 195 feet above the base of the formation at the Flyaway Creek section (Figure 19).

20. 76-KRE-24, 442 feet above the base of the formation at Knorr Range East section (Figure 33).

The results of a geochemical study prepared by Geochem Laboratories (Canada) Ltd. are enclosed as an appendix in this report.

GEOCHEMICAL SERVICE REPORT

039 01 06 041

HYDROCARBON SOURCE FACIES ANALYSIS

SELECTED OUTCROP SAMPLES

PEEL PLATEAU REGION, NWT

GeoChem Laboratories (Canada) Ltd.

Prepared

For

BP Exploration Limited

Calgary, Alberta

CONFIDENTIAL

January, 1977

4758 14 ST. N.E. CALGARY, ALBERTA T2E 6L7

COMPANY PROPRIETARY

HYDROCARBON SOURCE FACIES ANALYSIS
SELECTED OUTCROP SAMPLES
PEEL PLATEAU REGION, NWT

Prepared
For
BP Exploration Limited
Calgary, Alberta

CONFIDENTIAL
January, 1977

HYDROCARBON SOURCE FACIES ANALYSIS

SELECTED OUTCROP SAMPLES

PEEL PLATEAU REGION, NWT

SUMMARY

An organic geochemical study involving twenty (20) outcrop samples from the Peel Plateau Region, NWT has indicated the following:

- Most of the samples studied are rated in terms of their geothermal (time-temperature) maturation as very mature (stage 3 to 4-). Notable exceptions include Samples C147-019 and 020 which are rated respectively as moderately mature (stage 2) to moderately immature (stage 2- to 2).

- Most of the samples studied are also rated as very poor oil, but good to excellent dry gas (methane) source rocks. Traps laterally contiguous with source rocks of this nature should contain dry gas (provided that such traps have not been breached since migration and accumulation of the gas occurred). In cooler parts of the basin (possibly up depositional dip) extensions of such source units should have the potential for liquid hydrocarbon generation. Sample C147-010 is rated as a fair oil and good condensate and associated dry gas source rock whereas Sample C147-019 is rated as a good oil and associated dry gas source rock.

- Most of the samples contain significant amounts of sulphur. Hydrocarbon products generated from these rocks should contain appreciable amounts of sulphur compounds.

C. M. James
General Manager
GEOCHEM LABORATORIES (CANADA) LTD.

TABLE OF CONTENTS

INTRODUCTION

This report summarizes the results of organic geochemical analyses carried out on a suite of outcrop samples selected from the Peel Plateau Region, N.W.T.

The purpose of this study has been to:

- investigate the hydrocarbon source rock quality (richness, type) (gas versus oil), and state of thermal maturity (pre-oil generative, oil generative, or eometamorphosed) of the sediments in the samples studied.

This study was authorized by Dr. B. Chi, BP Exploration Limited.

Analytical

Twenty (20) outcrop samples were submitted for analysis. On arrival at GeoChem's Calgary laboratory these samples were assigned the GeoChem Job Number C147 followed by sample sequence numbers -001 through -20. (These samples have been grouped by Formation.) (Table I).

Each of the samples was described in terms of its gross lithology (Table IV; Figure 1). An organic carbon analysis was then performed on each sample (Table IV; Figure 1). All of the samples were subjected to C_{15+} soxhlet extraction. The C_{15+} extracts:acts were deasphaltened and the normal pentane soluble fraction of each extract was then subjected to quantitative and qualitative liquid chromatographic separation (which gives C_{15+} P-N (paraffin-naphthene) and AROM (aromatic) hydrocarbon and both sulphur and NSO (nitrogen, sulphur, and oxygen-bearing) nonhydrocarbon fractions). Extraction data are recorded in Tables Va, b and c and Figure 1. GC analyses were done on the C_{15+} P-N fraction of each extract where possible (Table VI; Figure 2). Visual kerogen assessments and vitrinite reflectance measurements were done on each of the samples. The visual kerogen assessment data are summarized in Table VII and on Figure 1. The vitrinite reflectance measurements are summarized in Table VIII and also on Figure 1 and Figure 3.

A brief description of the standard analytical procedures used in this study is presented in Appendix A for the benefit of the more interested reader. Interpretative charts are presented in Appendix B. All analytical data, whether used in the interpretation of this report or not, are recorded in Tables I through VIII. These data are, for the most part, also plotted in Figures 1 and 2. Figure 1 is a plot of geochemical parameters (total organic carbon, C_{15+} extractable bitumen, visual kerogen and vitrinite reflectance) which reflect source richness. These data are normally used in

Table I

IDENTIFICATION

Formation	GeoChem Sample Number	BP Sample Number
A	C147-005	76-PRE-9
	C147-006	76-PW-7
	C147-012	76-SC-7
	C147-013	76-RC-6
	C147-014	76-RC-10
	C147-015	76-RC-11
	C147-016	76-RC-20
	C147-017	76-RC-27
	C147-018	76-RR-2
B	C147-001	76-BC-5
	C147-003	76-KRE-5
	C147-011	76-SC-1-C
C	C147-002	76-BC-13
	C147-007	76-PW-9
D	C147-004	76-KRE-24
	C147-008	76-FCS-1
	C147-009	76-FCS-5
	C147-010	76-FC'A'-12
	C147-019	76-RRN-3
	C147-020	76-RRN-9

conjunction with the various geochemical indices of thermal maturation (i.e., C_{15+} P-N/AROM hydrocarbon ratio, composition of the C_{15+} P-N hydrocarbon fraction, and visual kerogen colour of the plant cuticle), to assess the hydrocarbon source character of the sediments. The GC chromatograms resulting from the analysis of the C_{15+} P-N (paraffin-naphthene or saturate fraction) hydrocarbon are shown on Figure 2 along with a GC chromatogram of the analysis of our standard oil sample.

An additional set of all figures is appended in a pocket at the rear of the report in order to aid the reader in cross-referencing the text with illustrated data.

General Information

Ten (10) copies of this report have been sent to BP Exploration. GeoChem retains one (1) copy of the report for possible future telephone conversations with authorized company personnel on specific details of this study. All data, interpretations, and other matters related to this study are considered highly confidential and the sole proprietorship of BP Exploration. Any questions related to this study should be directed to C. M. James, GeoChem Laboratories (Canada) Ltd.

RESULTS AND INTERPRETATIONS

For the purposes of presentation in this report, all of the samples studied have been grouped into four Formations A to D (Figure 1 and 2). All pertinent results are summarized in Table II.

A. State of Thermal Maturity

Formation A

The samples analysed from Formation A range from mature to severely altered, and are given a 3- to 4- index of thermal maturity. This rating is indicated by several geochemical indices of maturity including the following:

- the colour of organic matter as observed in our visual microscopic examinations of kerogen isolated from the samples (Table VII; Figure 1). Colours range from medium brown to black.

- the vitrinite reflectance (Av % R_o) values as measured by microscopic examination of vitrinite isolated from the sediment (Table VIII). These values range from 1.19 to 2.71.

Table II

Summary of Main Organic Geochemical Results

Formation	% OC	C_{15+} Extract ppm	C_{15+} Hydrocarbon ppm	Sulphur ppm	Kerogen Type	Kerogen Alteration 1-5 Scale	Av % R_o
A	3.8 9* (1.9 to 6.8)	160 9 (0 to 871)	26 9 (0 to 78)	65 9 (0 to 477)	NR	3- to 4-	1.51 9 (1.19 to 2.71)
B	1.07 3 (0.41 to 1.8)	205 3 (74 to 404)	31 3 (4 to 80)	73 3 (4 to 198)	Am;NR;H-W	3 to 3+	1.63 3 (1.40 to 1.81)
C	5.5 2 (4.3 to 6.7)	540 2 (163 and 917)	23 2 (20 and 26)	278 2 (28 and 528)	NR	3 to 4-	1.52 2 (1.32 to 1.72)
D	1.94 6 (0.70 to 3.5)	1002 6 (118 to 2446)	97 6 (12 to 263)	413 6 (30 to 1488)	NR;H-Am;W	2- to 3+	1.36 6 (0.52 to 2.04)

* Number of samples analysed.

NR - Non recognizable

C_{15}+ Hydrocarbon Richness Scale

0-	50 ppm	-	Very lean
50-	100 ppm	-	Lean
100-	200 ppm	-	Moderately rich
200-	800 ppm	-	Rich
800-	1,600 ppm	-	Very rich
	>1,600 ppm	-	Extremely rich

- the character of the nC_5 soluble portion of the total C_{15+} extract (Table V; Figure 1). Many of these samples (with the notable exception of C147-018) contain relatively small amounts of total hydrocarbon and NSO's. Note the high asphaltene/NSO ratio (Figure 1).

- the character of the C_{15+} P-N (paraffin-naphthene) hydrocarbon (Table VI; Figure 2a). Note that the P-N molecular distribution is skewed towards the high molecular end. Sample C147-005 has a pronounced odd carbon preference in the low molecular end. Normally an odd carbon preference is associated with less mature organic matter. Its presence in this sample would suggest that the type of organic matter present in the sample may be responsible.

Formation B

The samples analysed from Formation B are very mature, and are given a 3 to 3+ index of thermal maturity (Table VII; Figure 1). This rating is indicated by the same geochemical indices of maturity as for Formation A samples and include the following:

- the colour of organic matter as observed ranges from dark brown to black with a tinge of brown (Table VII).

- the vitrinite reflectance (Av % R_o) values range from 1.40 to 1.81 (Table VIII).

Formation C

The samples analysed from Formation C are very mature to severely altered, and are given a 3 to 4- index of thermal maturity. This rating is indicated by the same geochemical indices of maturity as for both Formation A and B samples and include the following:

- the colour of organic matter as observed ranges from dark brown to black (Table VII).

- the vitrinite reflectance (Av % R_o) values range from 1.32 to 1.72 (Table VIII).

Both the shape of the GC C_{15+} chromatograms and the P-N distribution of all of the samples in Formations A, B and C are quite similar (Figure 2). These similarities include:

- a relatively small amount of normal paraffins. Most of the P-N distribution is composed of naphthene.

- the P-N molecular distribution is skewed towards the low molecular end.

Formation D

The samples analysed from Formation D show the largest degree of variation in thermal maturity, ranging from moderately immature (C147-019 and 020) to very mature (C147-008 and 009). These samples are given a 2- to 3+ index of thermal maturity.

This rating is indicated by the following:

- the colour of plant cuticle, where observed, and by the colour of other organic matter where cuticular matter is not present. This colour ranges from orange brown (2- to 2 index of thermal maturity), through dark brown (3) and finally to black with a tinge of brown (3+) (Table VII).

- the vitrinite reflectance (Av % R_o) values range from 0.52 to 2.04 (Table VIII).

- the character of the nC_5 soluble portion of the total C_{15+} extract (Table V; Figure 1). Sample C118-004, 008 and 009 contain very poor amounts of C_{15+} hydrocarbon. Sample C147-020 contains a poor amount, sample C147-010 a fair amount, and sample C147-019 a good amount of C_{15+} hydrocarbon.

- the character of the C_{15+} P-N hydrocarbon (Table VI; Figure 2b). The chromatograms for samples C147-004, 008 and 009, are quite similar and closely resemble the other chromatograms for samples from Formations A, B, and C. These chromatograms are characterized by the relative absence of normal paraffins, and by the P-N distribution skewed towards the low molecular end, indicating a very mature thermal history. Sample C147-010 is characterized by a relative abundance of normal paraffins, by low carbon preference indices (Table VI), and by the pronounced P-N distribution skewed towards the low molecular end, all indicating a mature thermal history. Sample C147-079 is characterized by a moderate amount of normal paraffins (more than is present in C147-004, 008 or 009 but less thar in C147-010), and by the P-N distribution being skewed towards the low molecular end indicating a more moderately mature thermal history. Sample C147-020 appears at first glance (Figure 2b) to be quite similar to C147-019. Note however, the slight odd carbon preference, and the P-N molecular distribution skewed more towards the high molecular end indicating a moderately immature thermal history.

D. Hydrocarbon Source Quality

Formation A

The samples of Formation A without exception have good to excellent organic carbon content (Table IV; Figure 1) and in their present state appear to have generated only very poor to poor amounts of C_{15+} hydrocarbon (Table V; Figure 1). Considering their organic carbon content, their C_{15+} hydrocarbon content and their level of present maturation, it is suggested that at an earlier time these sediments did generate significant quantities of C_{15+} hydrocarbon, which has been subsequently destroyed by the relatively high geothermal regime to which these samples have been exposed. As a result, samples C147-013, 015 and 016 are rated as mature, very poor oil, but good to very good dry gas (methane) and possibly condensate source rocks. The remainder are rated as very mature to severely altered, very poor oil, but very good to excellent dry gas (methane) source rocks.

Formation B

The samples of Formation B have poor (C147-001) to fair (C147-003), to good (C147-011) organic carbon content (Table IV; Figure 1). All of these samples appear to have generated very poor to poor amounts of C_{15+} hydrocarbon (Table V). Considering their levels of maturation, their organic carbon content and their present C_{15+} hydrocarbon content, the samples from Formation B are rated in the following manner:

- C147-001 Very mature, very poor oil and associated gas source rock.
- C147-003 Very mature, very poor oil and fair associated gas source rock.
- C147-011 Very mature, very poor oil and good dry gas (methane) source rock.

Formation C

Both samples of Formation C have excellent organic carbon content (Table IV; Figure 1), but appear to have generated very poor amounts of C_{15+} hydrocarbon (Table V; Figure 1). These samples are rated as very mature to severely altered very poor oil, but excellent thermal gas source rocks.

Formation D

The samples of Formation D have fair (C147-009 and 020), to good (C147-010 and 019) to very good (C147-004 and 008) organic carbon content (Table IV; Figure 1). Samples C147-004, 008 and 009 appear to have generated very poor amounts of C_{15+} hydrocarbon (Table V; Figure 1): sample C147-020 has generated poor, sample C147-010 fair, and sample C147-019 good amounts of C_{15+} hydrocarbon. Based on their state of thermal maturity, organic carbon content, and C_{15+} hydrocarbon content, the samples of Formation D are rated as follows:

- C147-004 and 008 Very mature, very poor oil, but very good dry gas (methane) source rocks.
- C147-009 Very mature, very poor oil and only fair dry gas (methane) source rock.
- C147-010 Mature, fair oil and good associated condensate and dry gas (methane) source rock.
- C147-019 Moderately mature, good oil and associated dry gas (methane) source rock.
- C147-020 Moderately immature, poor oil, and fair dry gas (methane) source rock.

C. Exploration Significance of Results

In summary, the results of this study indicate that in general most of the samples studied are very mature, very poor oil, but good to excellent dry gas (methane) source rocks. Individual source ratings are presented for each sample studied in Table III. Traps laterally contiguous with source rocks of this nature should contain dry gas, unless they have been breached since migration of the gas occurred. In cooler parts of the basin, (possibly up depositional dip), extensions of such source units should have the potential for liquid hydrocarbon generation.

Sample C147-010 is rated as a fair oil, and good condensate and associated dry gas source rock. Laterally contiguous traps with source rocks of this nature should contain condensate and dry gas (unless of course, they have been breached). In cooler parts of the basin (again, possibly up depositional dip), extensions of such a source unit should have the potential for good liquid hydrocarbon genration. Sample C147-C19 is rated as a good oil and associated dry gas source rock. Laterally contiguous traps with source rocks of this nature should contain oil and associated dry gas.

Many of the samples studied from all four Formations contain significant amounts of sulphur in the nC_5 soluble portion of the total C_{15+} extract (Table V; Figure 1). It should be expected, therefore, that any hydrocarbon product generated from these source rocks will contain appreciable amounts of sulphur compounds.

Table III

Present Hydrocarbon Source Rating

GeoChem Sample Number	Oil Source Potential	Condensate Source Potential	Dry Gas Source Potential
Formation A			
C147-005	VP	P	VG
C147-006	VP	P	Ex
C147-012	VP	P	Ex
C147-013	VP	F?	G
C147-014	VP	P	Ex
C147-015	VP	F?	VG
C147-016	VP	F?	VG
C147-017	VP	P	VG
C147-018	VP	P	Ex
Formation B			
C147-001	VP	P	VP
C147-003	VP	P	F
C147-011	VP	P	G
Formation C			
C147-002	VP	P	Ex
C147-007	VP	P	Ex
Formation D			
C147-004	VP	P	VG
C147-008	VP	P	VG
C147-009	VP	P	F
C147-010	F	G	G
C147-019	G	VP	G
C147-020	P	VP	F

VP - Very poor
P - Poor
F - Fair
G - Good
VG - Very good
Ex - Excellent

Table IV

Organic Carbon Analyses and Gross Lithological Description

GeoChem Sample Number	Identification	Gross Lithological Description	GSA Color Code	Total Organic Carbon (% of Rock)
C147-001	76-BC-5	Shale, well compacted, blocky to fissile, micaceous, in part pyritic, calcareous, dark gray.	N3	0.41
C147-002	76-BC-13	Slate, fissile, hard, brittle, micromicaceous, very bituminous, non calcareous, grayish black.	N2	6.70
C147-003	76-KRE-5	Shale, well compacted, brittle, fissile, (cleavage surfaces curved, slickensides?), micaceous, non calcareous, medium dark gray.	N4	0.99
C147-004	76-KRE-24	Shale, hard, fissile, micaceous, non calcareous, brownish black, iron rich (pyrite?), weathers rusty brown.	5YR2/1	3.20
C147-005	76-PRE-9	Shale, well compacted, blocky to fissile, micromicaceous, non calcareous, grayish black.	N2	2.80, 2.72R
C147-006	76-PW-7	Shale, (silty), well consolidated, blocky, hard, micaceous, very bituminous, slightly calcareous, brownish black to grayish black.	N2 to 5YR2/1	4.15
C147-007	76-PW-9	Slate, hard, brittle, bituminous, slightly calcareous, brownish black.	5YR2/1	4.30
C147-008	76-FCS-1	Shale, well consolidated, blocky to fissile, non calcareous, dark gray.	N3	3.47
C147-009	76-FCS-15	Shale, well consolidated, blocky to fissile, non calcareous, dark gray.	N3	0.83
C147-010	76-FC'A'-12	Shale, good consolidation, fissile, micaceous, non calcareous, dark brownish gray.	N3 to 5YR3/1	1.77, 1.74R
C147-011	76-SC-1-C	Shale, good consolidation, fissile to blocky, micromicaceous, calcareous, dark gray.	N3	1.80

Table IV cont'd.

Organic Carbon Analyses and Gross Lithological Description

GeoChem Sample Number	Identification		Gross Lithological Description	GSA Color Code	Total Organic Carbon (% of Rock)
C147-012	76-SC-7		Slate (silty), hard, brittle, fissile, cleaves easily), slightly calcareous, bituminous, cleavage surfaces coated with calcite crystals, grayish black.	N2	4.49
C147-013	76-RC-6		Shale, hard, fissile, finely laminated, cleaves easily, calcareous, dark brownish gray.	5YR3/1 to N3	1.92
C147-014	76-RC-10		Slate? (silty), hard, fissile, quite brittle, cleaves easily, finely laminated, calcareous, bituminous, dark gray.	N3	4.70
C147-015	76-RC-11		Shale, well consolidated, fissile, finely laminated, calcareous, micaceous, dark brownish gray.	N3 to 5YR3/1	2.57, 2.56R
C147-016	76-RC-20		Shale (silty), hard, well consolidated, fissile, micaceous, slightly calcareous, dark gray.	N3	2.66
C147-017	76-RC-27		Slate? (silty), hard, brittle, fissile to blocky, cleaves easily, micaceous in part, non calcareous, grayish black.	N2	4.01
C147-018	76-RR-2		Shale (silty), hard, blocky, calcite on cleavage surfaces, slightly calcareous, (graptolite-rich), dark gray.	N3	6.83
C147-019	76-RRN-3		Shale, good consolidation, blocky to fissile, varied, non calcareous, alternate bands of dark brownish gray and medium brownish gray shale.	N3 + 5YR3/1 and N5 + 5YR5/1	1.68
C147-020	76-RRN-9	A	95% Shale, good consolidation, moderately soft, blocky , non calcareous, light to medium olive gray.	5Y5/1 to 5Y6/1	0.70, 0.69R
		B	5% Siltstone, hard, blocky, non calcareous, light gray with thin laminae of light olive gray.	N7 + 5Y6/1	

Table V

Summary of C_{15}+ Soxhlet Extraction, Deasphaltening and Liquid Chromatography

A. Weights of Extracts and Chromatographic Fractions

GeoChem Sample Number	Identification	Weight of Rock Extd. (grams)	Total Extract (grams)	Precipitated Asphaltenes (grams)	N-C5 Soluble (grams)	Sulfur (grams)	Paraffins-Naphthenes (grams)	Aromatics (grams)	Eluted NOS'S (grams)	Noneluted NSO'S (grams)
C147-001	76-BC-5	50.10	0.0036	0.0028	0.0008	0.0002	0.0002	0.0003	0.0001	0.0001
C147-002	76-BC-13	49.60	0.0455	0.0171	0.0284	0.0262	0.0005	0.0005	0.0007	0.0005
C147-003	76-KRE-5	50.08	0.0202	0.0046	0.0156	0.0099	0.0017	0.0023	0.0016	0.0001
C147-004	76-KRE-24	50.00	0.0057	0.0035	0.0022	0.0015	0.0005	0.0001	0.0002	0.0001
C147-005	76-PRE-9	50.22	0.0054	0.0028	0.0026	0.0016	0.0004	0.0005	0.0001	0.0001
C147-006	76-PW-7	50.48	0.0103	0.0042	0.0061	0.0039	0.0007	0.0006	0.0004	0.0005
C147-007	76-PW-9	50.58	0.0081	0.0049	0.0032	0.0014	0.0008	0.0005	0.0005	0.0001
C147-008	76-FCS-1	41.12	0.1006	0.0341	0.0665	0.0612	0.0007	0.0002	0.0040	0.0004
C147-009	76-FCS-15	50.32	0.0154	0.0039	0.0115	0.0088	0.0009	0.0013	0.0002	0.0003
C147-010	76-FC'A'-12	50.18	0.0524	0.0317	0.0207	0.0091	0.0055	0.0022	0.0001	0.0038
C147-011	76-SC-1-C	50.32	0.0068	0.0056	0.0012	0.0008	0.0001	0.0001	0.0000	0.0002
C147-012	76-SC-7	50.74	0.0038	0.0024	0.0014	-	0.0001	0.0004	0.0007	0.0002
C147-013	76-RC-6	Extract below calculation limits								
C147-014	76-RC-10	50.17	0.0019	0.0013	0.0006	-	0.0002	0.0001	0.0002	0.0001
C147-015	76-RC-11	Extract below calculation limits								
C147-016	76-RC-20	Extract below calculation limits								
C147-017	76-RC-27	50.76	0.0442	0.0164	0.0278	0.0242	0.0003	0.0006	0.0005	0.0022
C147-018	76-RR-2	43.52	0.0063	0.0016	0.0047	-	0.0029	0.0005	0.0005	0.0008
C147-019	76-RRN-3	50.13	0.0832	0.0376	0.0456	0.0272	0.0030	0.0102	0.0014	0.0038
C147-020	76-RRN-9	50.42	0.0219	0.0122	0.0097	0.0029	0.0013	0.0030	0.0003	0.0022

Table V cont'd.

B. Concentration of Extracted Materials in Rock

GeoChem Sample Number	Identification	Total Extract (ppm)	Hydrocarbons			Sulfur (ppm)	Nonhydrocarbons			
			Paraffin-Naphthene (ppm)	Aromatic (ppm)	Total (ppm)		Preciptd. Asphaltene (ppm)	Eluted NSO'S (PPM)	Noneluted NSO'S (ppm)	Total (ppm)
C147-001	76-BC-5	74	4	6	10	4	56	2	2	60
C147-002	76-BC-13	917	10	10	20	528	345	14	10	369
C147-003	76-KRE-5	404	34	46	80	198	92	32	2	126
C147-004	76-KRE-24	118	10	2	12	30	70	4	2	76
C147-005	76-PRE-9	110	8	10	18	32	56	2	2	60
C147-006	76-PW-7	204	14	12	26	77	83	8	10	101
C147-007	76-PW-9	163	16	10	26	28	97	10	2	109
C147-008	76-FCS-1	2446	17	5	22	1488	829	97	10	936
C147-009	76-FCS-15	307	18	26	44	175	78	4	6	88
C147-010	76-FC'A'-12	1046	111	44	155	181	632	2	76	710
C147-011	76-SC-1-C	137	2	2	4	16	111	2	4	117
C147-012	76-SC-7	75	2	8	10	-	47	14	4	65
C147-013	76-RC-6	Extract below calculation limits								
C147-014	76-RC-10	38	4	2	6	-	26	4	2	32
C147-015	76-RC-11	Extract below calculation limits								
C147-016	76-RC-20	Extract below calculation limits								
C147-017	76-RC-27	871	6	12	18	477	323	10	43	376
C147-018	76-RR-2	144	67	11	78	-	37	11	18	66
C147-019	76-RRN-3	1660	60	203	263	543	750	28	76	854
C147-020	76-RRN-9	436	26	60	86	58	242	6	44	292

Table V cont'd.

C. Composition of Extracts

GeoChem Sample Number	Identification	Hydrocarbons: Paraffin-Naphthene %	Hydrocarbons: Aromatic %	PN/Arom	Sulfur %	Nonhydrocarbons: Eluted NSO'S %	Nonhydrocarbons: Noneluted NSO'S %	Nonhydrocarbons: Precipitd. Asphaltene %	Asph/NSO	HC'S %	HC/Non HC
C147-001	76-BC-5	5.6	8.3	0.67	5.6	2.8	2.8	74.9	14.00	13.9	0.16
C147-002	76-BC-13	1.1	1.1	1.00	57.6	1.5	1.1	37.6	14.25	2.2	0.02
C147-003	76-KRE-5	8.4	11.4	0.74	49.0	7.9	0.5	22.8	2.71	19.8	0.25
C147-004	76-KRE-24	8.8	1.8	5.00	26.3	3.5	1.8	57.8	11.67	10.5	0.11
C147-005	76-PRE-9	7.4	9.3	0.80	29.6	1.9	1.9	49.9	14.00	16.7	0.20
C147-006	76-PW-7	6.8	5.8	1.17	37.9	3.9	4.9	40.7	4.67	12.6	0.14
C147-007	76-PW-9	9.9	6.2	1.60	17.3	6.2	1.2	59.2	8.17	16.0	0.19
C147-008	76-FCS-1	0.7	0.2	3.50	60.8	4.0	0.4	33.9	7.75	0.9	0.01
C147-009	76-FCS-15	5.8	8.4	0.69	57.3	1.3	1.9	25.3	7.80	14.3	0.17
C147-010	76-FC'A'-12	10.5	4.2	2.50	17.4	0.2	7.3	60.4	8.13	14.7	0.17
C147-011	76-SC-1-C	1.5	1.5	1.00	11.8	1.5	2.9	80.8	8.67	2.9	0.03
C147-012	76-SC-7	2.6	10.5	0.25	-	18.4	5.3	63.2	2.67	13.2	0.19
C147-013	76-RC-6	Extract below calculation limits									
C147-014	76-RC-10	10.5	5.3	2.00	-	10.5	5.3	68.4	4.33	15.8	0.19
C147-015	76-RC-11	Extract below calculation limits									
C147-016	76-RC-20	Extract below calculation limits									
C147-017	76-RC-27	0.7	1.4	0.50	54.7	1.1	5.0	37.1	6.07	2.0	0.02
C147-018	76-RR-2	46.1	7.9	5.80	-	7.9	12.7	25.4	1.23	54.0	1.17
C147-019	76-RRN-3	3.6	12.3	0.29	32.7	1.7	4.6	45.1	7.23	15.9	0.19
C147-020	76-RRN-9	5.9	13.7	0.43	13.2	1.4	10.0	55.8	4.88	19.6	0.24

TABLE VI

SATURATE HYDROCARBON ANALYSES

NORMALISED PARAFFIN DISTRIBUTION

	C147-001	C147-002	C147-003
nC_{15}	-	0.8	-
nC_{16}	-	1.4	-
nC_{17}	-	1.9	2.6
ip-C_{19}	-	1.8	2.0
nC_{18}	-	4.2	6.6
ip-C_{20}	-	2.1	6.9
nC_{19}	3.7	10.0	14.7
nC_{20}	12.7	14.9	16.3
nC_{21}	18.0	11.8	13.8
nC_{22}	22.5	14.0	13.8
nC_{23}	25.4	10.3	14.7
nC_{24}		8.1	-
nC_{25}	-	7.0	-
nC_{26}	-	2.9	-
nC_{27}	-	2.6	-
nC_{28}	-	0.8	-
nC_{29}	7.0	0.8	3.0
nC_{30}	3.1	0.6	2.3
nC_{31}	4.8	-	3.3
nC_{32}	1.7	-	-
nC_{33}	1.1	-	-
nC_{34}	-	-	-
nC_{35}	-	-	-
% Paraffin	4.42	9.49	2.52
% Isoprenoid	-	0.41	0.27
% Naphthene	95.58	90.10	97.21
CP Index A			
CP Index B			
ip-C_{19}/ip-C_{20}	-	0.87	0.29

TABLE VI cont'd.

SATURATE HYDROCARBON ANALYSES

NORMALISED PARAFFIN DISTRIBUTION

	C147-004	C147-005	C147-006
nC_{15}	-	-	-
nC_{16}	-	-	-
nC_{17}	0.8	0.4	0.9
$ip\text{-}C_{19}$	0.5	0.4	1.5
nC_{18}	3.8	0.9	7.7
$ip\text{-}C_{20}$	1.9	0.6	7.7
nC_{19}	20.5	2.8	21.0
nC_{20}	23.2	7.7	23.7
nC_{21}	12.9	8.1	13.7
nC_{22}	9.4	8.0	10.8
nC_{23}	9.2	11.2	6.4
nC_{24}	-	3.9	1.8
nC_{25}	-	9.2	0.9
nC_{26}	-	3.8	0.9
nC_{27}	-	14.9	0.7
nC_{28}	3.5	3.4	-
nC_{29}	3.8	10.8	-
nC_{30}	3.5	2.5	-
nC_{31}	3.5	8.5	-
nC_{32}	2.2	1.1	-
nC_{33}	1.3	1.8	-
nC_{34}	-	-	-
nC_{35}	-	-	-
% Paraffin	5.03	10.71	9.02
% Isoprenoid	0.17	0.08	0.93
% Naphthene	94.80	89.21	90.05
CP Index A			
CP Index B			
$ip\text{-}C_{19}/ip\text{-}C_{20}$	0.29	0.60	0.20

TABLE VI cont'd.

SATURATE HYDROCARBON ANALYSES

NORMALISED PARAFFIN DISTRIBUTION

	C147-007	C147-008	C147-009
nC_{15}	-	1.3	1.4
nC_{16}	-	2.1	2.9
nC_{17}	3.6	4.5	4.8
$ip\text{-}C_{19}$	2.6	4.5	2.9
nC_{18}	11.2	9.4	3.8
$ip\text{-}C_{20}$	12.1	9.4	2.4
nC_{19}	14.3	16.0	5.3
nC_{20}	14.0	19.3	12.0
nC_{21}	9.3	11.8	17.2
nC_{22}	8.8	13.4	22.5
nC_{23}	9.0	8.3	24.8
nC_{24}	-	-	-
nC_{25}	-	-	-
nC_{26}	-	-	-
nC_{27}	4.5	-	-
nC_{28}	2.6	-	-
nC_{29}	2.6	-	-
nC_{30}	1.9	-	-
nC_{31}	2.1	-	-
nC_{32}	1.4	-	-
nC_{33}	-	-	-
nC_{34}	-	-	-
nC_{35}	-	-	-
% Paraffin	4.45	3.86	2.48
% Isoprenoid	0.74	0.64	0.15
% Naphthene	94.81	95.50	97.37
CP Index A			
CP Index B			
$ip\text{-}C_{19}/ip\text{-}C_{20}$	0.22	0.49	1.20

TABLE VI cont'd.

SATURATE HYDROCARBON ANALYSES

NORMALISED PARAFFIN DISTRIBUTION

	C147-010	C147-011	C147-017
nC_{15}	-	0.3	2.0
nC_{16}	-	0.6	3.3
nC_{17}	0.2	0.8	4.6
ip-C_{19}	0.2	0.6	3.9
nC_{18}	2.9	0.8	3.9
ip-C_{20}	0.5	0.8	2.0
nC_{19}	8.7	5.2	5.3
nC_{20}	13.2	13.8	5.9
nC_{21}	14.9	20.7	9.1
nC_{22}	14.2	28.1	13.2
nC_{23}	12.1	28.3	46.0
nC_{24}	9.6	-	-
nC_{25}	7.6	-	-
nC_{26}	5.4	-	-
nC_{27}	4.0	-	-
nC_{28}	2.4	-	-
nC_{29}	1.7	-	-
nC_{30}	1.1	-	-
nC_{31}	0.6	-	-
nC_{32}	0.3	-	-
nC_{33}	0.2	-	-
nC_{34}	0.1	-	-
nC_{35}	0.1	-	-
% Paraffin	40.43	5.38	2.43
% Isoprenoid	0.33	0.09	0.20
% Naphthene	59.24	94.53	97.37
CP Index A	1.07		
CP Index B	1.13		
ip-C_{19}/ip-C_{20}	0.38	0.67	2.00

TABLE VI cont'd.

SATURATE HYDROCARBON ANALYSES

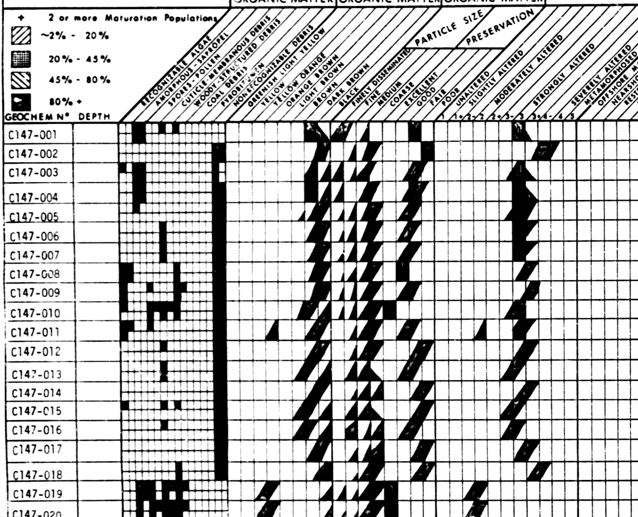
NORMALISED PARAFFIN DISTRIBUTION

	C147-018	C147-019	C147-020
nC_{15}	3.3	-	-
nC_{16}	4.4	-	-
nC_{17}	5.5	-	-
$ip\text{-}C_{19}$	6.6	-	-
nC_{18}	5.5	0.7	-
$ip\text{-}C_{20}$	1.1	0.7	-
nC_{19}	5.5	3.9	-
nC_{20}	6.6	8.6	3.6
nC_{21}	8.8	11.8	8.8
nC_{22}	13.2	12.6	10.2
nC_{23}	14.2	13.3	11.6
nC_{24}	13.2	10.3	8.9
nC_{25}	12.1	8.8	9.5
nC_{26}	-	7.1	6.3
nC_{27}	-	6.4	9.2
nC_{28}	-	4.7	7.3
nC_{29}	-	3.9	8.2
nC_{30}	-	3.1	5.8
nC_{31}	-	2.4	5.3
nC_{32}	-	1.1	3.1
nC_{33}	-	0.6	2.2
nC_{34}	-	-	-
nC_{35}	-	-	-
% Paraffin	0.93	8.05	7.64
% Isoprenoid	0.07	0.07	-
% Naphthene	99.00	91.88	92.36
CP Index A			
CP Index B			
$ip\text{-}C_{19}/ip\text{-}C_{20}$	6.00	-	-

C147

Table VII

GEOCHEM N°	DEPTH	TYPE OF ORGANIC MATTER / COLOR OF ORGANIC MATTER / STATE OF ORGANIC MATTER / MATURATION INDEX / DEPOSITIONAL ENVIRONMENT	REMARKS
C147-001			Am*;-;H-W
C147-002			NR
C147-003			Am;NR[2];-
C147-004			Am;NR[2];-
C147-005			NR[2];-;Am*
C147-006			NR[2];-;H?
C147-007			NR[2];-;H?
C147-008			Al?;NR[2];W
C147-009			NR[2];W?;Al-H
C147-010			H[1];NR[2]-W;Al
C147-011			NR[2];Al;H?
C147-012			NR[2];-;H?
C147-013			NR[2];-;H?
C147-014			NR[2];-;-
C147-015			NR[2];-;Al-H-W
C147-016			NR[2];H?;-
C147-017			NR[2];-;-
C147-018			NR[2];W?;-
C147-019			Am[1];W;H
C147-020			H;W;Am



1 Degraded herbaceous   2 NR - Woody or herbaceous??   * In part finely comminuted woody & herbaceous kerogen

Table VIII

Vitrinite Reflectance Summary

GeoChem Sample Number	Number of Particles Measured	Reflectivity % $\overline{R}$ min	$\overline{R}$ max	$\overline{R}$ aver	Comments
C147-001	10	1.15	2.40	1.67	Very low organic content. A few small particles of vitrinite. Many have botanical form.
C147-002	9 13	1.03	4.34	3.17 1.32	Low organic content. Some particles of high reflectance - probably inertinite. Wisps and impregnation of low reflectance material - probably bitumenite.
C147-003	13	1.37	2.68	1.81	Very low organic content. A few small particles of vitrinite - many show botanical form.
C147-004	20	0.82	2.08	1.35	Low organic content. Some good vitrinite wisps and stringers.
C147-005	20	0.97	1.99	1.44	Low organic content. A few interstitial areas and wisps - probably bitumenite. Rather poor surfaces.
C147-006	19	1.01	2.03	1.45	Low organic content. Interstitial areas with rather poor surfaces. Probably hydrocarbon residue. No true vitrinite.
C147-007	13	1.10	3.16	1.72	Low organic content. Small, ragged wisps of high reflecting material.
C147-008	20	1.40	2.30	1.92	Moderate organic content. Small wisps and interstitial areas of high reflecting material - vitrinite or bitumenite.
C147-009	20	1.17	2.89	2.04	Low organic content. A few isolated particles of vitrinite. Some show botanical form.
C147-010	20	1.20	2.17	1.67	Moderate organic content. Chiefly small, high reflectance particles and some small wisps.

Vitrinite Reflectance Summary

GeoChem Sample Number	Number of Particles Measured	Reflectivity % R min	R̄ max	R aver	Comments
C147-011	20	0.92	2.[illegible]1	1.40	Low organic content. A few vitrinite particles and interstitial areas of hydrocarbon residue.
C147-012	11	1.11	1.57	1.3[illegible]	Very low organic content. A few small wispy interstitial areas of hydrocarbon residue.
C147-013	19 1	0.91	2.[illegible]	1.28 2.01	Low moderate organic content. Small vitrinite wisps and thin stringers with occasional particles.
C147-014	12 8	.21	[illegible]	1.39 2.01	Low moderate organic content. Mixture of small, rather ragged wisps and particles. Vitrinite dominant.
C147-015	19 1	1.16	1.98	1.40 1.98	Low organic content. Tiny wisps and particles of vitrinite material. High reflectance - some reworking.
C147-016	20	0.90	2.13	1.19	Low organic content. Very small, rather ragged vitrinite wisps dominant. Also some small vitrinite particles.
C147-017	9 8	1.15	4.39	3.45 1.34	Low organic content. A few particles of very high reflectance - possibly inertinite. Wispy impregnation of lower reflectance.
C147-018	21	1.70	4.15	2.71	Low organic content. Interstitial areas and thin stringers of high reflecting material - possibly bitumenite.
C147-019	20	0.33	0.71	0.52	Low moderate organic content. Some good vitrinite wisps and particles. Also inertinite and spores visible. Vitrinite dominant.
C147-020	19 2	0.40	1.09	0.64 1.05	Low moderate organic content. Numerous small particles and wisps of vitrinite. Little inertinite but a lot of reworked material.

FIGURE 1

SOURCE CHARACTER

PRESENTATION OF ANALYTICAL DATA

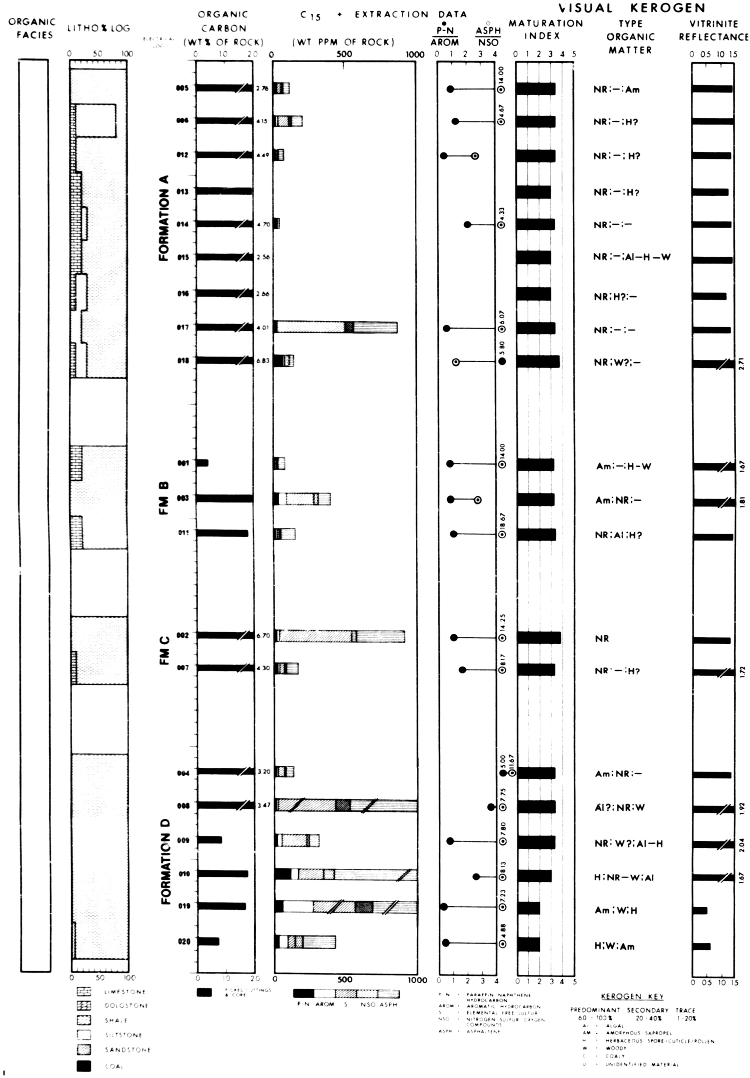


FIGURE 2A

C_{15} + SATURATE HYDROCARBONS

PRESENTATION OF ANALYTICAL DATA

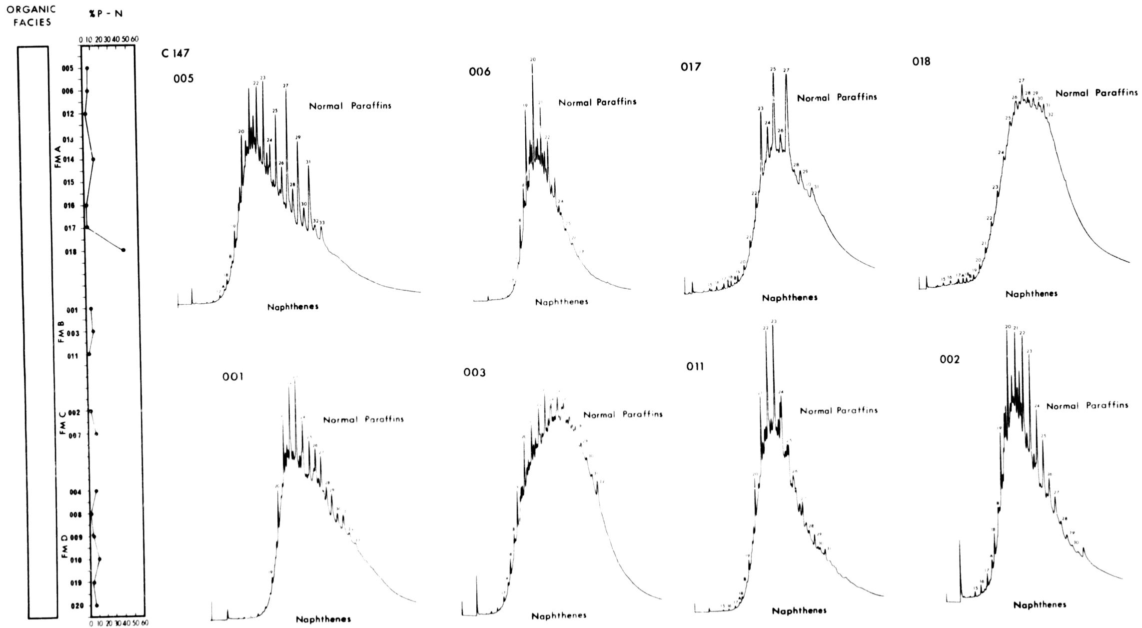


FIGURE 2B

C 15 + SATURATE HYDROCARBONS
PRESENTATION OF ANALYTICAL DATA

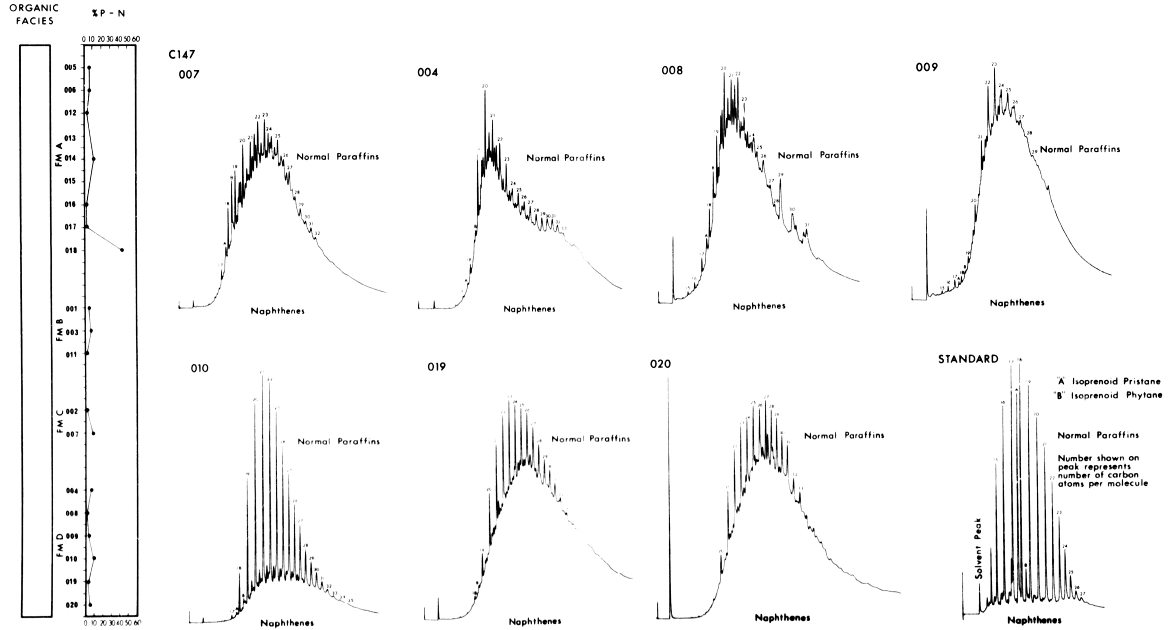
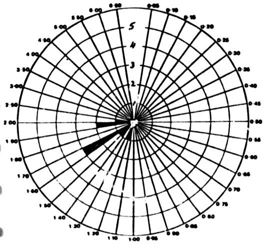


Figure 3

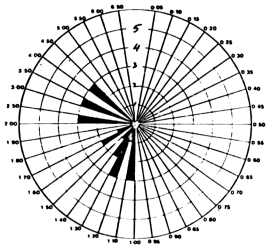
$\overline{R}$ aver = 1.67

No. of particles measure⟨' = 10



C147-001

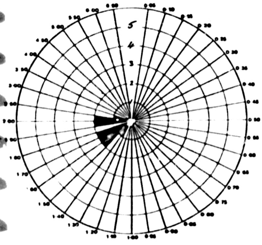
$\overline{R}$ aver = 1.32
No. of particles measured = 13
$\overline{R}$ aver = 3.17
No. of particles measured = 9



C147-002

$\overline{R}$ aver = 1.81

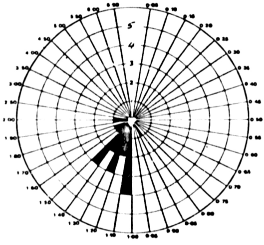
No. of particles measured = 13



C147-003

$\overline{R}$ aver = 1.35

No. of particles measured = 20

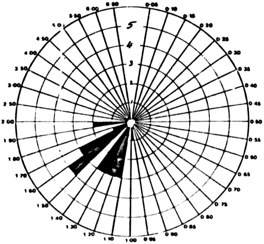


C147-004

Figure 3 cont'd.

$\overline{R}$ aver = 1.44

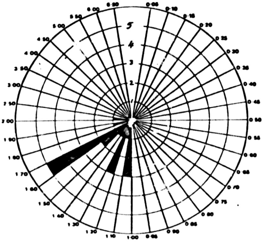
No. of particles measured = 20



C147-005

$\overline{R}$ aver = 1.45

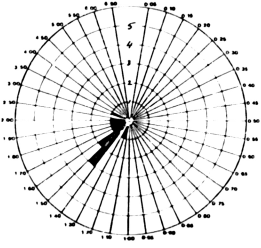
No. of particles measured = 19



C147-006

$\overline{R}$ aver = 1.72

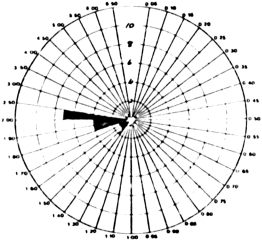
No. of particles measured = 13



C147-007

$\overline{R}$ aver = 1.92

No. of particles measured = 20

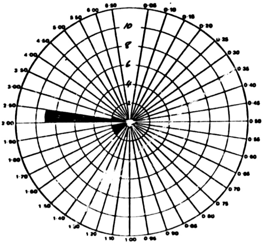


C147-008

Figure 3 cont'd.

$\overline{R}$ aver = 2.04

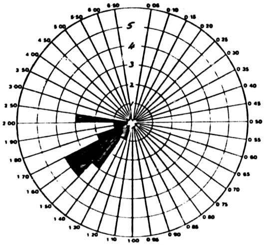
No. of particles measured = 20



C147-009

$\overline{R}$ aver = 1.67

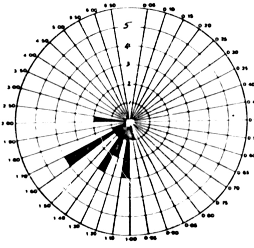
No. of particles measured = 20



C147-010

$\overline{R}$ aver = 1.40

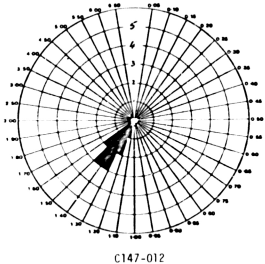
No. of particles measured = 20



C147-011

$\overline{R}$ aver = 1.37

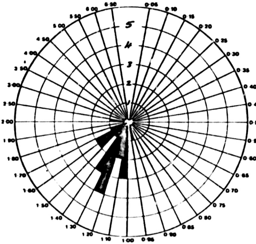
No. of particles measured = 11



C147-012

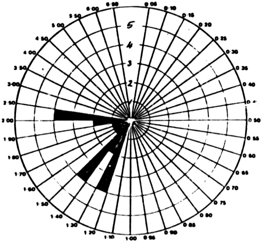
Figure 3 cont'd.

$\overline{R}$ aver = 1.28
No. of particles measured = 19
$\overline{R}$ aver = 2.01
No. of particles measured = 1



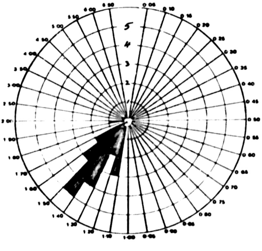
C147-013

$\overline{R}$ aver = 1.39
No. of particles measured = 12
$\overline{R}$ aver = 20.1
No. of particles measured = 8



C147-014

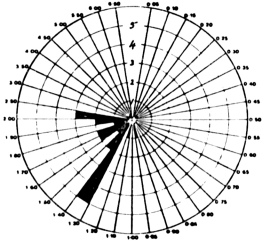
$\overline{R}$ aver = 1.40
No. of particles measured = 19
$\overline{R}$ aver = 1.98
No. of particles measured = 1



C147-015

$\overline{R}$ aver = 1.19

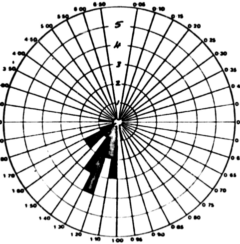
No. of particles measured = 20



C147-016

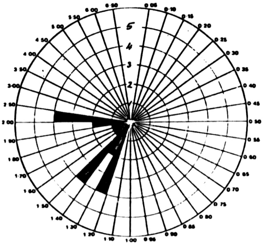
Figure 3 cont'd.

$\overline{R}$ aver = 1.28
No. of particles measured = 19
$\overline{R}$ aver = 2.01
No. of particles measured = 1



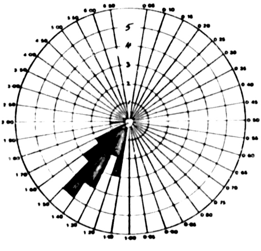
C147-013

$\overline{R}$ aver = 1.39
No. of particles measured = 12
$\overline{R}$ aver = 20.1
No. of particles measured = 8



C147-014

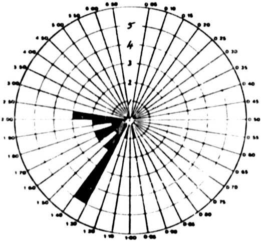
$\overline{R}$ aver = 1.40
No. of particles measured = 19
$\overline{R}$ aver = 1.98
No. of particles measured = 1



C147-015

$\overline{R}$ aver = 1.19

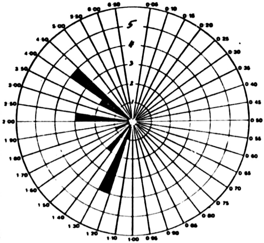
No. of particles measured = 20



C147-016

Figure 3 cont'd.

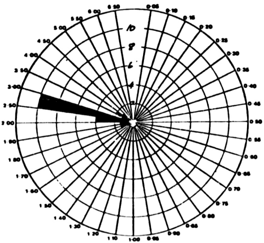
R̄ aver = 1.34
No. of particles measured = 8
R̄ aver = 3.45
No. of particles measured = 9



C147-017

R̄ aver = 2.71

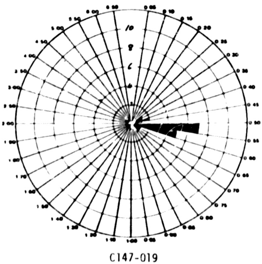
No. of particles measured = 21



C147-018

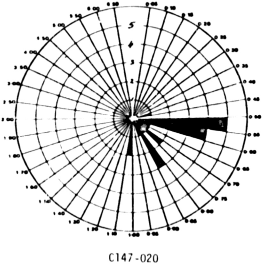
R̄ aver = 0.52

No. of particles measured = 21



C147-019

R̄ aver = 0.64
No. of particles measured = 19
R̄ aver = 1.05
No. of particles measured = 2



C147-020

APPENDIX A

BRIEF DESCRIPTION OF THE ANALYSES PERFORMED BY

GEOCHEM LABORATORIES (CANADA) LTD.

"Screen Analyses" are described in sections A and C, "Sample Preparation" in section B and "Follow-up Analyses" in sections C through H. The analyses can be run on either core or cuttings material with the proviso that samples must be canned for the C_1-C_7 analysis and should be canned (or sealed wet in a plastic bag) for the C_4-C_7 analysis. The other analyses can also be used on outcrop samples.

A) SAMPLE WASHING AND HAND PICKING

All of the analyses described in subsequent sections are run on washed and hand picked samples.

Cuttings are washed to remove the drilling mud, care being taken not to remove soft clays and fine sand during the washing procedure. Using the C_1-C_7 hydrocarbon data profile of the well, or the organic carbon profile (if this analysis is used for screening), electric logs (if supplied) and the appearance of the cuttings under the binocular microscope, samples are selected to represent the lithological and geochemical zones penetrated by the well. These samples are then carefully hand picked and the lithology of the uncaved material is described. It is these samples which are submitted for further analysis.

The remaining samples (also washed) are dried and packaged in labelled plastic bags for return to the client. Any hand picked sample remaining after analysis is also returned together with the extracted rock material.

Our reports normally incorporate a gross lithological description of all the samples which have been analysed and litho percentage logs are featured on all of the figures. As screen analyses are recommended at narrow intervals, a complete lithological profile is obtained.

B) ORGANIC CARBON ANALYSIS

The organic carbon content of a rock is a measure of its total organic richness. Combined with the visual kerogen, C_1-C_7, C_4-C_7 and C_{15+} analyses, the organic carbon content is used to evaluate the hydrocarbon source quality of the sediment. Not only is this analysis an integral part of a total evaluation, but it can also be used as an economical screen analysis for dry samples (when the C_1-C_7 analysis cannot be used).

Hand picked samples are dried, crushed and then acidised to remove the inorganic calcium and magnesium carbonates. The actual analysis involves combustion in a Leco carbon analyser. Blanks, standard and duplicates are run routinely for purposes of quality control at no extra cost to the client.

The data are tabulated and presented diagramatically in our reports in a manner which facilitates comparison with the gross lithology (see section B) of the samples.

C) C_{15+} EXTRACTION, DEASPHALTENING AND CHROMATOGRAPHIC SEPARATION

Sections "A" and "D" dealt with analyses covering the light end of the hydrocarbon spectrum. This section is concerned with the solvent extractable organic material in the rock with more than fourteen carbon atoms in the molecule (ie. the heavy end). The amount and composition of this fraction indicates source quality, source type, the level of thermal maturation and the possible presence of migrated hydrocarbons. The individual parts into which the total fraction is split, can be submitted for further analyses (carbon isotopes, gas chromatography, high mass spectroscopy) which are primarily designed to correlate crude oils to their parent source rocks (but also see section "F").

These results are integrated with those derived from the visual kerogen, organic carbon and C_4-C_7 analyses.

The techniques involved in this analysis have been designed to give very reproducible results. Hand picked samples are ground and then solvent extracted in a soxhlet apparatus with benzene-methanol (the solvent system can be adapted to client's specifications). The total extract obtained is then separated by column chromatography into the following fractions: paraffin-naphthene hydrocarbons, aromatic hydrocarbons, eluted NSO's (nitrogen-, sulphur-, and oxygen- containing non-hydrocarbons), non-eluted NSO's and precipitated ashpaltenes. Note that the non-hydrocarbons are split into three fractions instead of being reported as a gross value.

For convenience and thoroughness, these data are reported in three formats: the weights of the fractions, their p.p.m. abundance and the percentage composition of the total extract. The data are also presented diagramatically.

Upon completion of the study, the extracts and extracted rock are both returned to the client.

D) GC ANALYSIS OF C_{15+} PARAFFIN-NAPHTHENE HYDROCARBONS

The molecular composition of the heavy C_{15+} paraffin-naphthene hydrocarbons reflects source quality, source type, the degree of thermal maturation and the presence of migrated hydrocarbons. This analysis provides a useful cross-correlation with the visual kerogen, C_{15+} chromatography and light hydrocarbon (C_1-C_7, C_4-C_7) analyses.

The paraffin-naphthene hydrocarbons obtained by column chromatography are introduced into the gas chromatograph using a solid rod injection system to ensure that all of the sample, including the heaviest ends, is analysed. Excellent resolution of the individual normal paraffins and of the significant isoprenoids and other isoparaffins is achieved.

The normal paraffin carbon preference indices (C.P.I.) are calculated using the following formulae:

$$\text{C.P.I. A} = \frac{\dfrac{C_{21}+C_{23}+C_{25}+C_{27}}{C_{20}+C_{22}+C_{24}+C_{26}} + \dfrac{C_{21}+C_{23}+C_{25}+C_{27}}{C_{22}+C_{24}+C_{26}+C_{28}}}{2}$$

$$\text{C.P.I. B} = \frac{\dfrac{C_{25}+C_{27}+C_{29}+C_{31}}{C_{24}+C_{26}+C_{28}+C_{30}} + \dfrac{C_{25}+C_{27}+C_{29}+C_{31}}{C_{26}+C_{28}+C_{30}+C_{32}}}{2}$$

The chromatograms are reproduced in the report for use as visual fingerprints and in addition, the following data are tabulated: normalised normal paraffin distributions; proportions of paraffins, isoprenoids and naphthenes in the total paraffin-naphthene fraction; C.P.I. A and C.P.I. B; pristane to phytane ratio.

E) VISUAL KEROGEN ANALYSIS

Kerogen is the insoluble organic matter in rocks. Visual examination of the kerogen gives a direct measure of the level of thermal maturation and organic facies and indicates the source quality of the sediment. Source quality is confirmed using the analyses discussed above.

The type of hydrocarbon (oil or gas) generated by a source rock is a function of the types of organic matter present in the sediment and its level of thermal maturation. Both of these parameters are measured directly by this method.

Kerogen is separated from the inorganic rock matrix by methods which avoid oxidation of the organic matter. It is then mounted on a glass slide and examined under a high power microscope.

This examination gives the following data: the types (amorphous, algal, herbaceous etc.) and proportions of the organic matter present, the colour and hence level of thermal maturation of the organic matter and the state of preservation of the organic matter.

F) VITRINITE REFLECTANCE

Vitrinite reflectance, a relatively new tool in petroleum exploration, was adopted some years ago by the coal industry as a method of defining coal rank. In petroleum exploration the technique is used to define the state of thermal maturity of hydrocarbon source rocks and, therefore, the rocks petroleum generation history. It is a known fact that metamorphism of coal increases with depth in a similar manner to that of other sedimentary rocks. The degree of coalification, or coal rank, is generally measured by various chemical parameters, i.e, carbon content or content of volatile matter.

Coal, depending upon composition, is classified into four lithotypes; vitrain, fusain, clarain and durain. The lithotypes are further classified into microlithotypes based on their microscopic organic constituents. These micrcsopic organic constituents, called macerals, are components of the "micro-layers" of coal. Based on similarities in their petrographic properties they fall into three categories; vitrinite (rich in oxygen), exinite (rich in hydrogen), and inertine (rich in carbon). Vitrinite is customarily used in the coal industry for classification studies because it is the most characteristic, most frequently occurring, and most homogeneous petrographic constituent. In addition, it is easily isolated and commonly occurs as inclusions in clay and sandy sediments.

E) VISUAL KEROGEN ANALYSIS

Kerogen is the insoluble organic matter in rocks. Visual examination of the kerogen gives a direct measure of the level of thermal maturation and organic facies and indicates the source quality of the sediment. Source quality is confirmed using the analyses discussed above.

The type of hydrocarbon (oil or gas) generated by a source rock is a function of the types of organic matter present in the sediment and its level of thermal maturation. Both of these parameters are measured directly by this method.

Kerogen is separated from the inorganic rock matrix by methods which avoid oxidation of the organic matter. It is then mounted on a glass slide and examined under a high power microscope.

This examination gives the following data: the types (amorphous, algal, herbaceous etc.) and proportions of the organic matter present, the colour and hence level of thermal maturation of the organic matter and the state of preservation of the organic matter.

F) VITRINITE REFLECTANCE

Vitrinite reflectance, a relatively new tool in petroleum exploration, was adopted some years ago by the coal industry as a method of defining coal rank. In petroleum exploration the technique is used to define the state of thermal maturity of hydrocarbon source rocks and, therefore, the rocks petroleum generation history. It is a known fact that metamorphism of coal increases with depth in a similar manner to that of other sedimentary rocks. The degree of coalification, or coal rank, is generally measured by various chemical parameters, i.e, carbon content or content of volatile matter.

Coal, depending upon composition, is classified into four lithotypes; vitrain, fusain, clarain and durain. The lithotypes are further classified into microlithotypes based on their microscopic organic constituents. These microsopic organic constituents, called macerals, are components of the "microlayers" of coal. Based on similarities in their petrographic properties they fall into three categories; vitrinite (rich in oxygen), exinite (rich in hydrogen), and inertine (rich in carbon). Vitrinite is customarily used in the coal industry for classification studies because it is the most characteristic, most frequently occurring, and most homogeneous petrographic constituent. In addition, it is easily isolated and commonly occurs as inclusions in clay and sandy sediments.

In the vitrinite reflectance technique, the vitrinite particles and associated kerogen types are extracted from the sediment, drill cuttings, etc., using a series of acids. The extracted residue is then embedded in Bioplastic or Epoxy and polished using 0.05 micron aluminum oxide polishing compound. A high resolution microscope, calibrated with a known optical glass standard, is used to measure the reflectivity of the vitrinite particle. The measurement, expressed as $\%R_o$, is taken in oil using an oil immersion objective. The $\%R_o$ values are then summarized on individual histograms. The degree of thermal alteration is derived statistically by obtaining numerous individual observations for a given sample. In most instances 20 to 30 observations are adequate. The reason for a statistical approach is twofold: 1) to define the range of reflectivity of the vitrinite within a given sample and 2) to help deliniate contamination problems associated with caving and/or reworked debris.

The vitrinite reflectance technique has several advantages over other thermal maturation classifications in that it is 1) an absolute rather than a subjective measurement; 2) it is a rigorous analytical evaluation that accurately defines the state of thermal maturation of a given sediment in standardized quantitative terms; and 3) vitrinite reflectance is a universally accepted technique which is directly applicable to predicting oil and gas generation and preservation.

COMPARISON OF EOMETAMORPHIC CRITERIA

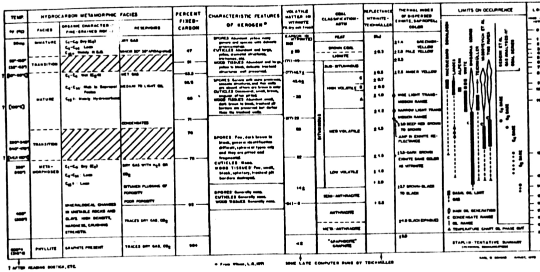


Figure 1

GEOTHERMAL DIAGENETIC CRITERIA

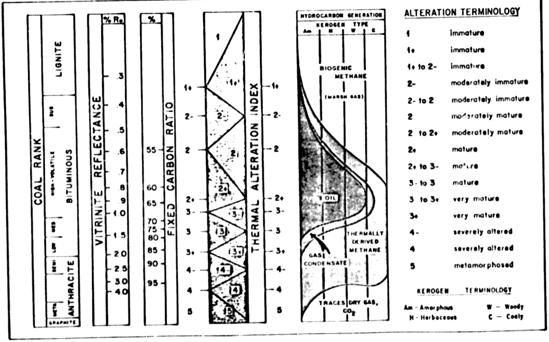


Figure 2

Source Quality Interpretative Diagram